AD-776 950

SURVEY OF TWO-BODY AND THREE-BODY REACTION-RATE COEFFICIENTS FOR THE IONIZED STRATOSPHERE AND MESOSPHERE

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March 1974

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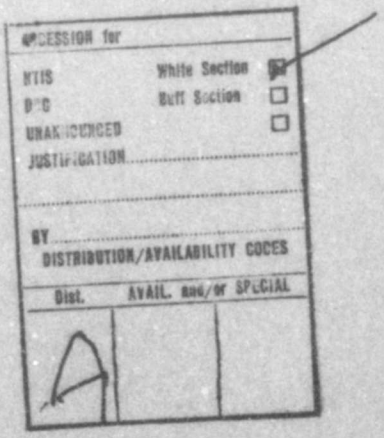

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SECURITY CLASSIFICATION OF THIS PAGE (When Data Entered)

REPORT DOCUMENTATION PAGE		READ INSTRUCTIONS BEFORE COMPLETING FORM
1. REPORT NUMBER REPORT NO. 1702	2. GOVT ACCESSION NO.	3. RECIPIENT'S CATALOG NUMBER
4. TITLE (and Subtitle) SURVEY OF TWO-BODY AND THREE-BODY REACTION-RATE COEFFICIENTS FOR THE IONIZED STRATOSPHERE AND MESOSPHERE		5. TYPE OF REPORT & PERIOD COVERED Final 6. PERFORMING ORG. REPORT NUMBER
7. AUTHOR(s) Franklin E. Niles		8. CONTRACT OR GRANT NUMBER(s)
9. PERFORMING ORGANIZATION NAME AND ADDRESS US Army Ballistic Research Laboratories Aberdeen Proving Ground, Maryland 21005		10. PROGRAM ELEMENT, PROJECT, TASK AREA & WORK UNIT NUMBERS RDT&E 1T161102B53A/15 DNA Subtask - S99QAXHD010
11. CONTROLLING OFFICE NAME AND ADDRESS U. S. Army Materiel Command 5001 Eisenhower Avenue Alexandria, VA 22304		12. REPORT DATE MARCH 1974 13. NUMBER OF PAGES 107
14. MONITORING AGENCY NAME & ADDRESS(if different from Controlling Office)		15. SECURITY CLASS. (of this report) UNCLASSIFIED 15a. DECLASSIFICATION/DOWNGRADING SCHEDULE

16. DISTRIBUTION STATEMENT (of this Report)

Approved for public release; distribution unlimited.

17. DISTRIBUTION STATEMENT (of the abstract entered in Block 20, if different from Report)

18. SUPPLEMENTARY NOTES

This research was jointly sponsored by:
a. Army Materiel Command-Army Project 1T161102B53A, Task 15, Aeronomy.
b. Defense Nuclear Agency-under Subtask No. S99QAXHD010, Work Unit #51, Work Unit Title "Applications of the AIRCHEM Code to Laboratory Experiments."

19. KEY WORDS (Continue on reverse side if necessary and identify by block number)

Atmospheric Chemistry
Atmospheric Deionization
Atmospheric Reactions
Chemical Reactions
Cluster Ions

20. ABSTRACT (Continue on reverse side if necessary and identify by block number)

Rate coefficients for two-body and three-body reactions applicable to the ionized stratosphere and mesosphere have been surveyed. The reactions are divided into five classes, viz., (1) positive-ion reactions, (2) electron reactions, (3) negative-ion reactions, (4) ion-ion reactions, and (5) neutral reactions. Reactions and their measured rate coefficients are given in tables and the values selected for inclusion in the AIRCHEM atmospheric deionization computer code are identified. The current status of knowledge regarding these reactions is summarized.

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(Item 19 Continued)

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Ionized Air
Ionospheric Chemistry
Ionospheric Reactions
Mesospheric Reactions
Rate Coefficients
Reaction Rates
Stratospheric Reactions
Two-Body Reactions
Three-Body Reactions

SUMMARY

Two-body and three-body reactions and their rate coefficients which occur in the ionized stratosphere and mesosphere following nuclear bursts have been surveyed. The reactions form most of the chemistry included in the AIRCHEM computer code and are intended to be appropriate for times up to an hour following the burst. They do not form the final or minimum set of reactions. The reactions are listed in five sections, viz., (1) positive-ion reactions, (2) electron reactions, (3) negative-ion reactions, (4) ion-ion reactions, and (5) neutral reactions. Tables give the reactions and their rate coefficients included in the AIRCHEM code, the rate coefficients given in the DNA Reaction Rate Handbook, and recent measurements or reviewed values. The tables also give the reactions and their rate coefficients which have deliberately been omitted from the AIRCHEM code.

The status of our knowledge of rate coefficients is as follows:

- Positive-ion reactions. Fairly well known at room temperature. Still need rate coefficients for possible reactions converting NO^+ into H_3O^+. Rate of ionization and dissociation important.

- Electron reactions. Three-body attachment of electrons to O_2 well known. Associative detachment known at room temperature only. Collisional detachment known only for O_2^-. Although photodetachment is outside the scope of this report, much additional work remains to be done.

- Negative-ion reactions. Rate coefficients for simple negative ions have been measured at room temperature. Most have not been measured enough times to say that they are established. Rate coefficients for multiple hydrated negative ions are not, in general, known. State or structure of the negative ion is important to rate coefficients and is often not known. Photodissociation and collisional dissociation, in general, are not known.

- Ion-ion reactions. Rate coefficients known only for simple ions. No measurements exist for cluster ions. Products could be important.

- Neutral reactions. For short-time responses, the pertinent rate coefficients are fairly well known. Initial concentrations of minor constituents, while not surveyed in this report, are poorly known and their uncertainties control the uncertainties in the reaction rates.

Most of the charged-particle reaction-rate coefficients have been measured within the past decade, principally as part of the Defense Nuclear Agency's Reaction Rate Program. The measurements of rate coefficients for neutral reactions have been stimulated by the Department

of Transportation's Climatic Impact Assessment Program. Continued stimulation is needed to insure that the remaining charged-particle and neutral reaction-rate coefficients are measured.

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INTRODUCTION

The earth's atmosphere is ionized by several types of radiation during the course of a day.[1*] In addition to the natural sources of ionization, the atmosphere can be ionized by different types of radiation from nuclear bursts.[2] The ionization, and accompanying excitation and dissociation, initiate reactions which form the chemistry of the atmosphere. The importance of a particular reaction varies with time and location, especially with altitude. This report surveys the two-body and three-body reactions occurring in the ionized stratosphere and mesosphere, the altitude region approximately between 15km and 85km.

The reactions listed in this report constitute most of the chemistry included in the AIRCHEM computer code under development at the Ballistic Research Laboratories. Not included are reactions involving photons as a reactant nor energetic particle reactions producing ionization, excitation, and/or dissociation. The chemistry has undergone a number of changes as new information became available. The current set of reactions is not the final word. From this observer's viewpoint, the rapid advances in laboratory measurements during the past decade seem to have slowed down. This unfortunate circumstance should allow this report to be disseminated before it becomes totally obsolete.

The prime source of information for reaction-rate information of the type needed for the AIRCHEM code is the Defense Nuclear Agency's Reaction Rate Handbook.[2] In this handbook, many more reactions are listed than deemed necessary for the AIRCHEM code. As usual in a field where active work is on-going, better values exist for some of the reactions than are given in the handbook. In this survey we give the rate coefficients listed in the handbook to identify changes from the handbook values, to point out the estimated uncertainty associated with each rate coefficient, and to indicate the data base on which the rate coefficients have been selected. Reactions whose rate coefficients have been estimated are clearly identified. These reactions are included in the AIRCHEM code even though measurements of their rate coefficients have not been made. To omit them is to assume that the rate coefficients are zero — an assumption which would be surely false. These estimated rate coefficients are the ones most urgently in need of measurement.

References are listed on page 29.

Only gas-phase reactions are given. So little is known about reactions on the surfaces of aerosols, or even what aerosols are present in the stratosphere and mesosphere, that we cannot say whether or not these types of reactions are important.

The reactions and their rate coefficients will be discussed in five sections. Section 1 presents the positive-ion reactions other than ionization, ion-electron recombination, and ion-ion recombination. Types of reactions presented are positive-ion charge transfer, positive ion-atom interchange, three-body positive-ion-neutral association, and positive-ion collisional dissociation. Section 2 presents the reactions involving electrons other than ionization and photodetachment. Types of reactions presented are three-body attachment, collisional detachment, associative detachment, dissociative attachment, and dissociative recombination. Section 3 presents the negative ion-reactions other than electron attachment, electron detachment, photodissociation, and ion-ion recombination. Types of reactions presented are negative-ion charge transfer, negative ion-atom interchange, three-body negative-ion-neutral association, and negative-ion collisional dissociation. Section 4 presents ion-ion recombination for positive ions and negative ions. Section 5 presents the reactions between neutral species. Types of reactions are radiative neutral recombination, three-body neutral recombination, neutral rearrangement, radiative electronic-state deexcitation, and collisional electronic-state quenching.

The species within the reactions are ordered as reactants or as products according to the listing in Table I. It is presumed that the measurements refer to ground state unless explictly indicated. The reactions are listed in the tables according to the reactant within each reaction appearing first in Table I with the exception that endothermic reactions are listed with the exothermic reaction involving the same species. The tables are devided into two parts. Those reactions included in the AIRCHEM code are given first and then those omitted are given.

As can be seen from Table I, 58 species are considered to undergo reactions in the AIRCHEM code. (The code can accommodate more species and more reactions with very little change in coding.) The symbol M is used to denote any third body. In the atmosphere, M can normally be considered to be N_2 and O_2 at altitudes of interest to this report.

Only the first hydrate of any of the negative ions is included in the AIRCHEM code. This is solely because of our lack of knowledge regarding the formation and destruction of hydrated negative ions. Multiple hydrates have been observed in laboratory experiments and in the mesosphere.

For very few of the reactions involving ions are there enough measurements to make a critical review. Especially needed are rate-coefficient measurements over the temperature range 150K to 600K.

Several reviews of neutral reactions have recently been given. These have been utilized to provide the rate coefficients given in Section 5.

1. POSITIVE-ION REACTIONS

Table II lists two-body and three-body, positive-ion reactions and their rate coefficients with the exception of initial ionization, excitation of ions, positive ion-electron recombination, and ion-ion recombination. Table II is in two parts. Part A gives the reactions in the current versions of the AIRCHEM computer code. Part B gives some of the reactions deliberately omitted from the AIRCHEM code. Figure 1 is a schematic representation of the reactions in Part A. A solid line indicates that the rate coefficient or equilibrium coefficient for the reaction connecting two species has been measured at room temperature. A dashed line indicates that the rate coefficient for a reaction connecting two species has been estimated.

Cosmic rays, energetic particles, X-rays, and gamma-rays can ionize all of the neutral constituents of the stratosphere and mesosphere; but, since N_2 and O_2 are by far the major constituents, the principal ions produced are N^+, N_2^+, O^+, and O_2^+. In the mesosphere, Lyman-α radiation ionizes the minor constituent NO. This is the dominant ionizing process between about 65km and 85km at mid-latitudes under normal conditions. Below 65km, ionization by cosmic rays is the dominant ionizing process under normal conditions.

The reactions readily divide into two sequences as illustrated in Figure 1. One sequence has NO^+ as the precursor ion; the other sequence has O_2^+ as the precursor ion. Before examining these two sequences, we will look at reactions other than direct ionization producing NO^+ and O_2^+.

In the atmosphere the reaction of N^+, N_2^+, and O^+ with any gas other than N_2 or O_2 can be neglected. First we will look at the reactions involving N^+. The reaction with O_2, reactions IIA9a and IIA9b, rapidly converts N^+ into O_2^+ and NO^+. Next, looking at the reactions involving N_2^+, we see that the reaction with O_2, reaction IIA23, converts N_2^+ into O_2^+ and will normally be more important than the reaction with O, reactions IIA22a and IIA22b, over the altitude interval of concern in this report.

Both N^+ and N_2^+ can react with N_2 to form N_3^+ and N_4^+ via reactions IIB19 and IIB40a, respectively. Also N_3^+ is produced from N_2^+ via reaction

IIB39. Once produced, both N_3^+ and N_4^+ react rapidly with O_2 to form O_2^+ via reactions IIB44 and IIB45 so that the formation of N_3^+ or N_4^+ cannot alter subsequent reactions significantly. Hence N_3^+ and N_4^+ and their reactions are omitted from the AIRCHEM code.

The reaction of O^+ with O_2 via reaction IIA26 is straightforward; but the reaction of O^+ with N_2, reactions IIA24 and IIA25, is not. The two-body reaction of O^+ with N_2 to produce NO^+ has received a lot of experimental and theoretical attention. The rate of the reaction depends on the population of the vibrational states of N_2. For the altitude region of concern in this report, collisional quenching is sufficiently rapid that only the lowest vibrational level is included. The three-body reaction of O^+ with N_2 to produce NO^+ has received very little attention.

Let us examine the rate coefficient for the three-body reaction in more detail. The only measured value is 5.4×10^{-29} cm^6/sec at 82°K with He as the third body. We would like to know the rate coefficient at 300°K with N_2 as the third body. We can obtain an approximate value by assuming reaction IIA25 is analogous to other three-body, positive-ion-neutral association reactions.

The effect of the third-body on positive-ion-neutral association reactions is revealed in Table III. We have enough information on the four reactions indicated to determine mean values for the ratios of the rate coefficients with either Ar, O_2, N_2, or NO as the third body to the rate coefficient with He as the third body. This provides a factor by which the rate coefficient obtained with He as the third body needs to be multiplied in order to obtain the rate coefficient with N_2 as the third body. The factor is about 4. This factor should be used to convert all rate coefficients for positive-ion-neutral-association reactions measured with He as the third body into rate coefficients suitable for atmospheric calculations. Similarly the same factor, about 4, is needed to convert collisional-dissociation rate coefficients measured with He as the third body into rate coefficients suitable for atmospheric calculations. Likewise the rate coefficients measured with Ar or O_2 as the third bodies should be multiplied by a factor of 1.5 to obtain atmospheric values.

The temperature dependence is given in the Reaction Rate Handbook[2] as $(T/300)^{-1^{+1}_{-2}}$. To go from 82°K to 300°K results in an unacceptably broad spread. Examining the reported measurements, we find that O_2^+

reacting with O_2 to form O_4^+, reaction IIA33a, N^+ reacting with N_2 to form N_3^+, reaction IIB19, and N_2^+ reacting with N_2 to form N_4^+, reaction IIB40a, have been measured at both 82°K and 300°K. For reaction IIA33a the mean value at 300°K is 2.65×10^{-30} cm^6/sec with O_2 as the third body. For He as the third body, the value becomes 1.77×10^{-30} cm^6/sec using the correction factor of 1.5. Consequently the ratio of rate coefficients at 80°K and 300°K is 17.5 for reaction IIA33a.

Assuming the 280°K value of Bohme *et al.*[3] is the same as the 300°K values of reactions IIB19 and IIB40a, the ratios of rate coefficients at 82°K and 300°K are 8.4 and 6.3, respectively. Bohme *et al.* also give the rate coefficients for the reaction $Ar^+ + Ar + M \rightarrow Ar_2^+ + M$ with He as the third body. The ratio of rate coefficients at 82°K and 300°K is 17.5. The mean value for the ratio for these four reactions is 12.4. This suggests that the temperature dependence for positive-ion-neutral association is close to $(T/300)^{-2}$.

Using these correction factors, the rate coefficient for the three-body reaction of O^+ with N_2 at 300°K with N_2 as the third body is about 1.6×10^{-29} cm^6/sec. Comparisons of reaction frequencies for O^+ reacting with N_2 to form NO^+ in a two-body reaction and in a three-body reaction, reactions IIA24 and IIA25, respectively, are given in Table IV for altitudes of 20, 40, 60, and 80km. The three-body reaction is seen to be more important in the stratosphere and the two-body reaction is more important in the mesosphere. Experimental verification is needed.

The reactions from N^+, N_2^+, and O^+ have created NO^+ and O_2^+. Now O_2^+ can be converted into NO^+ by reaction with N, reaction IIA28, reaction with NO, reaction IIA29, and possibly reaction with N_2, reaction IIA31. The two-step process of O_2^+ reacting with NO_2 to form NO_2^+, reaction IIA30, followed by NO_2^+ reacting with NO, reaction IIA21, also converts O_2^+ into NO^+.

In analyzing the relative importance of the two sequences, one with O_2^+ as the precursor ion and the other with NO^+ as the precursor ion, an important question is whether the rates of formation of NO^+ from O_2^+ are greater than the rates for the formation of O_4^+. In the stratosphere and mesosphere, they normally are not. If NO^+ were not formed from the ionization of NO by Lyman-α radiation, then the NO^+ sequence would definitely be secondary to the O_2^+ sequence. In the nuclear disturbed

atmosphere, the NO^+ sequence can become important as well as the O_2^+ sequence.

The formation of O_4^+ occurs two ways. The direct formation is by the association of O_2^+ and O_2, reaction IIA33a. The rate coefficient for this reaction may need to be multiplied by the factor 1.5 to account for N_2 being the dominant third body in the atmosphere. On the other hand, since the reactants are homonuclear and homonuclear reactions tend to be faster than heteronuclear reactions, a correction factor may not be necessary. The indirect formation of O_4^+ occurs through the association of O_2^+ and N_2 forming $O_2^+(N_2)$, reaction IIA32a, followed by a switching reaction with O_2, reaction IIA37. Considering both the third-body effect and the indirect path, the formation of O_4^+ from O_2^+ could be about twice that normally employed in atmospheric models.[5,6,7]

The continuation of the O_2^+ sequence depends on the ratio of the concentration of atomic oxygen to that of water vapor. If the ratio exceeds 5, the sequence is stopped by the reaction of O_4^+ with O, reaction IIA41. If not, the reaction of O_4^+ with H_2O, reaction IIA38a, continues the sequence. In the upper part of the mesosphere, the concentration ratio of O to H_2O probably exceeds 5.[5]

In Figure 1 we show that O_4^+ and $O_2^+(H_2O)$ can react with NO and NO_2 via reactions IIA35, IIA39, and IIA40. The rate coefficients for these charge transfer reactions have not been measured. The concentration of H_2O should exceed the concentration of either NO or NO_2 by orders of magnitude. Hence these reactions do not hinder the formation of the hydrated protons.

The main flow of charge is from $O_2^+(H_2O)$ to $H_3O^+(OH)$ to $H^+(H_2O)_2$ via reactions IIA34b and IIA3, respectively. A lesser flow of charge is from $O_2^+(H_2O)$ to H_3O^+ via reaction IIA34a and then to $H^+(H_2O)_2$ directly via reaction IIA1a or indirectly through $H_3O^+(N_2)$ to $H^+(H_2O)_2$ via reactions IIA2a and IIA5, respectively. Similar indirect paths may occur between the higher proton hydrates. However, the chemical equilibrium ultimately established between the higher proton hydrates would probably be affected very little.

The hydrated protons can also be produced from NO^+. The only observed reaction connecting the hydrated NO^+ with the hydrated protons is reaction of $NO^+(H_2O)_3$ with H_2O, reaction IIA18. Since there

is a need for a rapid conversion between NO^+ and the hydrated protons in the normal D region reaction of $NO^+(H_2O)$ with HO and/or HO_2, reactions IIA14 and IIA15, have been proposed.[8,9,10] The rapid conversion of NO^+ to H_3O^+ also requires the rapid formation of $NO^+(H_2O)$. The direct formation via reaction of NO^+ with H_2O, reaction IIA11, is too slow; however, the indirect formation through $NO^+(N_2)$ and $NO^+(CO_2)$ using the recent measurements of Heimerl and Vanderhoff[11] may be sufficiently rapid. The major uncertainty is the collisional breakup of $NO^+(N_2)$. The outstanding problems in the positive-ion reactions of the stratosphere and mesosphere are the establishment of an additional sink for NO^+ and the establishment of an additional source for H_3O^+ and hydrates. Current ideas have attempted to solve these problems by creating a fast path between NO^+ and H_3O^+.

2. ELECTRON REACTIONS

For many purposes the most important property of ionized air is the concentration of free electrons. Free electrons are created by several ionizing processes.[1,2] They are also released by detachment from negative ions. They are removed by attachment to neutral species to form negative ions and by recombination with positive ions. The latter process has neutral products and truly results in the loss of free electrons. The former process creates a reservoir of charge in the form of negative ions from which the electron can be removed.

The omission of photodetachment in this report means that one of the most important atmospheric processes will not be discussed. This is an area of considerable interest at this time as are other detachment processes, for example, collisional detachment, for which very little experimental data exist.

Reactions involving an electron are given in Table V. Electrons combine readily with positive ions via different ion-electron recombination processes. Except for highly ionized regions where collisional-radiative recombination, reaction VB3, VB4, VB6, VB7, VB10, and VB11, can become important, the most important recombination process in the ionized stratosphere and mesosphere is dissociative recombination. Three-body ion-electron recombination, reaction VB12, can become important in the ionized troposphere.

The rate coefficients for dissociative recombination divide roughly into two groups. Those involving positively-charged cluster ions have values in the 10^{-6} cm^3/sec range. Those involving diatomic and triatomic molecular ions have values in the 10^{-7} cm^3/sec range. Experimental identification of the products of dissociative recombination has, in general, not been made.

The primary electron attachment process is three-body attachment to molecular oxygen reactions VA20a and VA21a. Only in rare cases will the saturated three-body attachment to NO_2, reaction VA19, and the dissociative attachment to O_3, reaction VA22, be important. After O_2^- is formed by three-body attachment, reactions as discussed in the following section form the other negative ions of the ionized stratosphere and mesosphere.

Associative detachment of the electron from O^- by CO, H_2, N, NO, O, and $O_2(^1\Delta_g)$ is quite rapid. Likewise associative detachment of the electron from O_2^- by N and O is quite rapid. Consequently, whenever the concentrations of these reactive neutral species are large, associative detachment will be important.

Collisional detachment has been measured only from O_2^-, reactions VA20b, VA21b, and VA31. Except for the last listed reaction, collisional detachment can be neglected in the normal stratosphere and mesosphere. For the nuclear disturbed case, collisional detachment may be important.[12]

3. NEGATIVE-ION REACTIONS

As mentioned in the preceding section, negative-ion reactions are initiated primarily by the three-body attachment of electrons to molecular oxygen forming O_2^-. Only under special conditions will the attachment to O_3 forming O^- and to NO_2 forming NO_2^- be important. Once O_2^- is formed reactions create the negative ions as illustrated in Figures 2, 3, and 4.

Figure 2 gives a schematic representation of the reactions which do not involve negatively charged cluster ions. Figure 3 shows the reactions which do involve the negatively charged cluster ions included in the AIRCHEM code. A solid line indicates that the rate coefficient for the reaction connecting two negative ions has been measured, although the product ion may not be unique. A dashed line indicates that the rate coefficient has been estimated. Figure 4 shows the reactions involving negatively charged cluster ions not yet included in the AIRCHEM code whose rate coefficients or equilibrium coefficients have been measured as well as those in Figures 2 and 3.

In these figures, the negative ion NO_3^- has been treated as an unclustered negative ion whereas its peroxy form, $OONO^-$, has been treated as a cluster ion. (In this report NO_3^{-*} is also used to denote $OONO^-$.) Different forms with the same mass for other negative ions exist. These are not differentiated in this report. The existence of different forms with the same mass will make the understanding of negative-ion chemistry of the ionized stratosphere and mesosphere challenging.

Notwithstanding the complexity of the chemistry of negative ions, we present in Table VI the reactions and rate coefficients for atmospheric negative ions as they are known today. A quick look at the references given in this table reveals that the rate coefficients have been measured within the last few years. The most prolific researchers have been the group headed by E. E. Ferguson at the National Oceanic and Atmospheric Administration in Boulder, Colorado. During the course of preparing this report, we asked for a value for CO_4^- reacting with O_3, reaction VIA9, which was unmeasured at the time, and they quickly responded. Unfortunately, that reaction was the last of the unmeasured important atmospheric negative-ion reactions whose rate coefficient could be measured easily.

The flow of charge in the figures is, in general, from O_2^- to the hydrates of NO_3^-. The concentrations of minor neutral constituents, principally H_2O, CO_2, NO, NO_2, O, and O_3, are very important to the formation of negative ions. Consequently, the dominance of any particular negative ion depends on the availability of particular neutral species to undergo reactions.

Measurements of the stratospheric negative ion composition have yet to be made. Those that have been made in the mesosphere are not in agreement.[13,14] Hence until more measurements of negative ion composition become available, the picture of negative-ion chemistry occurring in the ionized stratosphere and mesosphere will be formed primarily on the basis of laboratory information.

The altitude at which the cluster-ion-chemistry becomes important is primarily determined by the altitude at which the rate for O_2^- reacting with O_2 to form O_4^-, reaction VIA25a, exceeds the rate for O_2^- reacting with O_3 to form O_3^-, reaction VIA26. The rates are equal in the vicinity of 50-60km. Above this altitude, the short-term chemistry is dominated by simple negative ions. Below this altitude, the negative-ion chemistry is dominated by cluster ions.

What information do we need from the laboratory? First, the form or state of the negative ions needs to be determined for the reactions, both as reactants and as products. Second, the processes and rates by which one form of a negative ion changes into another form need to be determined. Third, the influence of photons through photodetachment and photodissociation needs to be determined as a function of wavelength. Fourth, the influence of elevated temperatures possibly causing collisional detachment and collisional dissociation needs to be determined. Fifth, rate coefficients for reactions of multiple hydrated negative ions with minor neutral species need to be measured. Sixth, rate coefficients for positive ion-negative ion recombination (vide infra) need to be measured. Seventh, third-body and temperature dependences of the rate coefficients need to be determined.

4. ION-ION REACTIONS

Table VII lists rate coefficients for ion-ion recombination. The theoretical investigations of Huestis[15] seem to indicate that most rate coefficients for two-body ion-ion recombination will be 2×10^{-7} cm^3/sec within a factor of 2. Except for those few reactions whose rate coefficients have been measured, this value has been assumed.

In the AIRCHEM code there are 21 positive ions and 14 negative ions. To include all possible two-body ion-ion recombination reactions would require that 294 reactions be included. Most of these would never be important. We have taken the approach that only the five hydrated protons, NO^+, and O_2^+ will ever react with a negative ion faster than with a neutral species. We let these 7 positive ions react with each of the 14 negative ions so that we list 98 ion-ion reactions. We give only one set of neutral products, although more than one are generally possible. The set picked may not be the most likely set. Neutral chemistry will probably dominate the formation of neutrals so that an exact description of the products of ion-ion recombination may not be necessary. Work is needed to verify this.

What is almost certainly true is that ion-ion recombination involving a hydrated proton will yield at least one odd hydrogen molecule. The molecule may be H, HO, HO_2, or HNO_3. Thus ion-ion recombination or ion-electron recombination along with the release of HO due to positive ion reactions, reactions IIA34a or IIA3, means that up to two odd hydrogen molecules will be formed per each ion pair produced by ionization.[16]

In the lower stratosphere, three-body ion-ion recombination may be more important than two-body recombination. Since there are no measurements for atmospheric ions and the theoretical values are little more than estimates, we see no compelling reason to include three-body ion-ion recombination at this time in the AIRCHEM code.

5. NEUTRAL REACTIONS

The Climatic Impact Assessment Program (CIAP) of the Department of Transportation has given considerable impetus to the measurement and review of neutral reactions involving atmospheric constituents. The National Bureau of Standards (NBS) has published several critical evaluations of neutral reactions as part of their involvement in CIAP. Prior to and coincident with the NBS work, the group headed by D. L. Baulch at the University, Leeds, England published a series of critical evaluations of high temperature reaction rate data. Other critical reviews have recently been made, notably those by V. N. Kondratiev, K. Schofield, and W. E. Wilson, Jr. The values given

in these reviews, in the DNA Reaction Rate Handbook[2], and recent measurements are given in Table VIII.

The neutral reactions included in the AIRCHEM code are those which may affect the chemistry of charged particles shortly after the stratosphere or mesosphere has been ionized. Consequently, reactions involving hydrocarbons and those with long time constants have been omitted.

The neutral chemistry can conveniently be divided into three classes, viz., (1) odd hydrogen chemistry, (2) odd nitrogen chemistry, and (3) odd oxygen chemistry. Odd hydrogen species are H, HO, HO_2, HNO_2, and HNO_3. Odd nitrogen species are $N(^2D)$, N, NO, NO_2, HNO_2, and HNO_3. Odd oxygen species are $O(^1D)$, O, and O_3. Within each class the chemistry can be divided into three types, viz., (1) reactions which create the odd species, (2) reactions which destroy the odd species, and (3) reactions which rearrange the odd species.

In general the formation of the odd species can be traced back to the photodissociation of H_2O for odd hydrogen and O_2 for odd oxygen. The formation of odd nitrogen can be traced back to reactions of energetic species with N_2, N_2O, or O_2.

Neutral reactions, other than photodissociation, creating odd hydrogen are:

$$O(^1D) + H_2 \rightarrow H + HO \qquad \text{(VIII A 3)}$$

$$O(^1D) + H_2O \rightarrow HO + HO \qquad \text{(VIII A 4)}$$

$$H_2O_2 + O \rightarrow HO + HO_2 \ . \qquad \text{(VIII A 45)}$$

Reaction (A 44) in Table VIII has been found to be too slow to be important.

As mentioned previously, charged particle reactions produce odd hydrogen. In the stratosphere where cosmic ray ionization occurs during the night as well as during the day, these reactions are a continuing small source of odd hydrogen. The reactions have been shown to be important in the mesosphere[16] during the time of increased particle flux. They can be important in nuclear disturbed regions. The reactions are:

$$H_3O^+(HO) + H_2O \rightarrow H^+(H_2O)_2 + HO \qquad \text{(II A 3)}$$

$$NO^+(H_2O)_3 + H_2O \rightarrow H^+(H_2O)_3 + HNO_2 \qquad \text{(II A 18)}$$

$$O_2^+(H_2O) + H_2O \rightarrow H_3O^+ + HO + O_2 \qquad \text{(II A 34 a)}$$

$$H^+(H_2O)_n + e \rightarrow H + nH_2O \qquad \text{(V A 1-7)}$$

$$H^+(H_2O)_n + X^- \rightarrow H + nH_2O + X \ . \qquad \text{(VII A 1-60)}$$

A schematic representation of the odd hydrogen chemistry is shown in Figure 5. The interconnection of two species by reactions is shown by the solid lines with the arrowhead pointing to a product and the tail coming from a reactant. The destruction of odd hydrogen is primarily the return to H_2O. A lesser amount goes to H_2 and H_2O_2. Some is lost through aerosol formation and HNO_3 precipitation. The reactions destroying odd hydrogen are:

$$H + H + M \rightarrow H_2 + M \qquad \text{(VIII A 18)}$$

$$H + HO \rightarrow H_2 + O \qquad \text{(VIII A 19)}$$

$$H + HO + M \rightarrow H_2O + M \qquad \text{(VIII A 20)}$$

$$H + HO_2 \rightarrow H_2 + O_2 \qquad \text{(VIII A 21b)}$$

$$H + HO_2 \rightarrow H_2O + O \qquad \text{(VIII A 21c)}$$

$$HNO_2 + HO \rightarrow H_2O + NO_2 \qquad \text{(VIII A 28)}$$

$$HNO_3 + HO \rightarrow H_2O + NO_2 + O \text{ (or } NO_3) \qquad \text{(VIII A 29)}$$

$$HO + HO \rightarrow H_2O + O \qquad \text{(VIII A 30)}$$

$$HO + HO + M \rightarrow H_2O_2 + M \qquad \text{(VIII A 31)}$$

$$HO + HO_2 \rightarrow H_2O + O_2 \qquad \text{(VIII A 32)}$$

$$HO_2 + HO_2 \rightarrow H_2O_2 + O_2 \qquad \text{(VIII A 40)}$$

Several reactions convert one odd hydrogen species into another. These are:

$$CO + HO \rightarrow CO_2 + H \qquad \text{(VIII A 16)}$$

$$H + HO_2 \rightarrow HO + HO \qquad \text{(VIII A 21a)}$$

$$H + H_2O_2 \rightarrow HO + H_2O \qquad \text{(VIII A 22a)}$$

$$H + H_2O_2 \rightarrow HO_2 + H_2 \qquad \text{(VIII A 22b)}$$

$$H + NO_2 \rightarrow HO + NO \qquad \text{(VIII A 23)}$$

$$H + N_2O \rightarrow HO + N_2 \qquad \text{(VIII A 24)}$$

$$H + O + M \rightarrow HO + M \qquad \text{(VIII A 25)}$$

$$H + O_2 + M \rightarrow HO_2 + M \qquad \text{(VIII A 26)}$$

$$H + O_3 \rightarrow HO + O_2 \qquad \text{(VIII A 27}$$

$$HO + H_2 \rightarrow H + H_2O \qquad \text{(VIII A 33)}$$

$$HO + H_2O_2 \rightarrow HO_2 + H_2O \qquad \text{(VIII A 34)}$$

$$HO + N \rightarrow H + NO \qquad \text{(VIII A 35)}$$

$$HO + NO_2 + M \rightarrow HNO_3 + M \qquad \text{(VIII A 36)}$$

$$HO + O \rightleftarrows H + O_2 \qquad \text{(VIII A 37)}$$

$$HO + O + M \rightarrow HO_2 + M \qquad \text{(VIII A 38)}$$

$$HO + O_3 \rightarrow HO_2 + O_2 \qquad \text{(VIII A 39)}$$

$$HO_2 + NO \rightarrow HO + NO_2 \qquad \text{(VIII A 41)}$$

$$HO_2 + O \rightarrow HO + O_2 \qquad \text{(VIII A 42)}$$

$$HO_2 + O_3 \rightarrow HO + 2O_2 \; . \qquad \text{(VIII A 43)}$$

Taken by themselves, reactions VIII A 39 and VIII A 42 form a pair in which HO acts like a catalyst. The net effect is $O + O_3 \rightarrow 2O_2$. Thus the odd hydrogen chemistry is closely coupled to the odd oxygen chemistry.

Odd nitrogen species are created by energetic particles. Reactions, other than ionization, dissociation, and excitation, creating odd nitrogen are:

$$O(^1D) + N_2O \rightarrow NO + NO \qquad \text{(VIII A 6)}$$

$$N_2^+ + O \rightarrow NO^+ + N(^2D) \qquad \text{(II A 22a)}$$

$$N_2^+ + O \rightarrow NO^+ + N \qquad \text{(II A 22b)}$$

$$O^+ + N_2 \rightarrow NO^+ + N \qquad \text{(II A 24)}$$

$$O^+ + N_2 + M \rightarrow NO^+ + N + M \qquad \text{(II A 25)}$$

$$O_2^+ + N_2 \rightarrow NO^+ + NO \; . \qquad \text{(II A 31)}$$

A schematic representation of the odd nitrogen chemistry is shown in Figure 6. The destruction of odd nitrogen is through the return to N_2 and N_2O and through the continuation of reactions via HNO_3 into aerosol formation and precipitation. The latter processes take a greater amount of time and are beyond the scope of this report. The reactions destroying odd nitrogen are:

$$N + N + M \rightarrow N_2 + M \qquad \text{(VIII A 46)}$$

$$N + NO \rightarrow N_2 + O \qquad \text{(VIII A 47a)}$$

$$N + NO \rightarrow O(^1D) + N_2 \qquad \text{(VIII A 47b)}$$

$$N + NO_2 \rightarrow N_2O + O \qquad \text{(VIII A 48b)}$$

Note that all four reactions require atomic nitrogen whose concentration is very small in the normal stratosphere and mesosphere.

Several reactions convert one odd nitrogen species into another. These are:

$$N(^2D) + O_2 \rightarrow NO + O \qquad \text{(VIII A 1)}$$

$$H + NO_2 \rightarrow HO + NO \qquad \text{(VIII A 23)}$$

$$HNO_2 + HO \rightarrow H_2O + NO_2 \qquad \text{(VIII A 28)}$$

$$HNO_3 + HO \rightarrow H_2O + NO_2 + O(\text{or } NO_3) \qquad \text{(VIII A 29)}$$

$$HO + N \rightarrow H + NO \qquad \text{(VIII A 35)}$$

$$HO + NO_2 + M \rightarrow HNO_3 + M \qquad \text{(VIII A 36)}$$

$$HO_2 + NO \rightarrow HO + NO_2 \qquad \text{(VIII A 41)}$$

$$N + NO_2 \rightarrow NO + NO \qquad \text{(VIII A 48a)}$$

$$N + O + M \rightarrow NO + M \qquad \text{(VIII A 49)}$$

$$N + O_2 \rightarrow NO + O \qquad \text{(VIII A 50)}$$

$$N + O_3 \rightarrow NO + O_2 \qquad \text{(VIII A 51)}$$

$$NO + NO + O_2 \rightarrow NO_2 + NO_2 \qquad \text{(VIII A 52)}$$

$$NO + O \rightarrow NO_2 + h\nu \qquad \text{(VIII A 53)}$$

$$NO + O + M \rightarrow NO_2 + M \qquad \text{(VIII A 54)}$$

$$NO + O_3 \rightarrow NO_2 + O_2 \qquad \text{(VIII A 55)}$$

$$NO_2 + O \rightarrow NO + O_2 \quad . \qquad \text{(VIII A 56)}$$

Taken by themselves, reactions VIII A 55 and VIII A 56 form a pair in which NO acts like a catalyst. The net effect is $O + O_3 \rightarrow 2O_2$. Thus odd nitrogen chemistry, like odd hydrogen chemistry, is closely coupled to the odd oxygen chemistry.

The primary source of atomic oxygen is the photodissociation of O_2 or O_3. The primary source of O_3 is the reaction of atomic oxygen with molecular oxygen via reaction VIII A 58. Reactions which create odd oxygen are:

$$N(^2D) + O_2 \rightarrow NO + O \qquad \text{(VIII A 1)}$$

$$H + HO \rightarrow H_2 + O \qquad \text{(VIII A 19)}$$

$$H + HO_2 \rightarrow H_2O + O \qquad \text{(VIII A 21c)}$$

$$HO + HO \rightarrow H_2O + O \qquad \text{(VIII A 30)}$$

$$N + NO \rightarrow N_2 + O \qquad \text{(VIII A 47a)}$$

$$N + NO \rightarrow O(^1D) + N_2 \qquad \text{(VIII A 47b)}$$

$$N + NO_2 \rightarrow N_2O + O \qquad \text{(VIII A 48b)}$$

$$N + O_2 \rightarrow NO + O \quad . \qquad \text{(VIII A 50)}$$

A schematic representation of the chemistry, other than photon processes, affecting odd oxygen is shown in Figure 7. The odd oxygen species are shown in block I. Since HO and NO have so great an effect on the odd oxygen species by acting as catalysts, they are shown in block II. The species outside blocks I and II are sources or sinks for odd oxygen and for HO and NO. Interconnecting reactions between the odd oxygen species, HO, and NO and reactions which contribute to the creation or destruction of these species are shown. The arrowhead points to a product species; the tail comes from a reactant species. One of the goals of CIAP is to determine the reactions and their rate coefficients for reactions affecting the O_3 concentration. CIAP considers several more reactions than shown here.

The reactions destroying odd oxygen are:

$$O(^1D) + H_2 \rightarrow H + HO \qquad \text{(VIII A 3)}$$

$$O(^1D) + H_2O \rightarrow HO + HO \qquad \text{(VIII A 4)}$$

$$O(^1D) + N_2 + M \rightarrow N_2O + M \qquad \text{(VIII A 5)}$$

$$O(^1D) + N_2O \rightarrow NO + NO \qquad \text{(VIII A 6)}$$

$$O(^1D) + O_3 \rightarrow O_2 + O_2 \qquad \text{(VIII A 8)}$$

$$CO + O + M \rightarrow CO_2 + M \qquad \text{(VIII A 17)}$$

$$H + O + M \rightarrow HO + M \qquad \text{(VIII A 25)}$$

$$H + O_3 \rightarrow HO + O_2 \qquad \text{(VIII A 27)}$$

$$HO + O \rightarrow H + O_2 \qquad \text{(VIII A 37a)}$$

$$HO + O + M \rightarrow HO_2 + M \qquad \text{(VIII A 38)}$$

$$HO + O_3 \rightarrow HO_2 + O_2 \qquad \text{(VIII A 39)}$$

$$HO_2 + O \rightarrow HO + O_2 \qquad \text{(VIII A 42)}$$

$$HO_2 + O_3 \rightarrow HO + 2O_2 \qquad \text{(VIII A 43)}$$

$$H_2O_2 + O \rightarrow HO + HO_2 \qquad \text{(VIII A 45)}$$

$$N + O + M \rightarrow NO + M \qquad \text{(VIII A 49)}$$

$$N + O_3 \rightarrow NO + O_2 \qquad \text{(VIII A 51)}$$

$$NO + O \rightarrow NO_2 + h\nu \qquad \text{(VIII A 53)}$$

$$NO + O + M \rightarrow NO_2 + M \qquad \text{(VIII A 54)}$$

$$NO + O_3 \rightarrow NO_2 + O_2 \qquad \text{(VIII A 55)}$$

$$NO_2 + O \rightarrow NO + O_2 \qquad \text{(VIII A 56)}$$

$$O + O + M \rightarrow O_2 + M \qquad \text{(VIII A 57)}$$

$$O + O_3 \rightarrow O_2(^1\Delta) + O_2 \qquad \text{(VIII A 59a)}$$

$$O + O_3 \rightarrow O_2 + O_2 \ . \qquad \text{(VIII A 59b)}$$

The rate for reaction VIII A 59 in the stratosphere is normally less than for the catalytic reaction involving NO and probably for the ones involving HO.

Reactions which convert one odd oxygen species into another are:

$$O(^1D) + O_2 \rightarrow O_2(^1\Sigma) + O \qquad \text{(VIII A 7)}$$

$$O(^1D) + M \rightarrow O + M \qquad \text{(VIII A 9)}$$

$$O_2(^1\Sigma) + O_3 \rightarrow O + 2O_2 \qquad \text{(VIII A 14)}$$

$$O + O_2 + M \rightarrow O_3 + M \ . \qquad \text{(VIII A 58)}$$

Reactions affecting HO and NO involving odd oxygen species have already been identified. Other reactions affecting HO and NO and shown on Figure 7 are:

$$CO + HO \rightarrow CO_2 + H \qquad \text{(VIII A 16)}$$

$$H + HO + M \rightarrow H_2O + M \qquad \text{(VIII A 20)}$$

$$H + HO_2 \rightarrow HO + HO \qquad \text{(VIII A 21a)}$$

$$H + H_2O_2 \rightarrow HO + H_2O \qquad \text{(VIII A 22a)}$$

$$H + NO_2 \rightarrow HO + NO \qquad \text{(VIII A 23)}$$

$$H + N_2O \rightarrow HO + N_2 \qquad \text{(VIII A 24)}$$

$$HNO_2 + HO \rightarrow H_2O + NO_2 \qquad \text{(VIII A 28)}$$

$$HO + HO + M \rightarrow H_2O_2 + M \qquad \text{(VIII A 31)}$$

$$HO + HO_2 \rightarrow H_2O + O_2 \qquad \text{(VIII A 32)}$$

$$HO + H_2 \rightarrow H + H_2O \qquad \text{(VIII A 33)}$$

$$HO + H_2O_2 \rightarrow HO_2 + H_2O \qquad \text{(VIII A 34)}$$

$$HO + N \rightarrow H + NO \qquad \text{(VIII A 35)}$$

$$HO + NO_2 + M \rightarrow HNO_3 + M \qquad \text{(VIII A 36)}$$

$$HO_2 + NO \rightarrow HO + NO_2 \qquad \text{(VIII A 41)}$$

$$N + NO_2 \rightarrow NO + NO \qquad \text{(VIII A 48a)}$$

$$NO + NO + O_2 \rightarrow NO_2 + NO_2 \; . \qquad \text{(VIII A 52)}$$

The reactions and their rate coefficients affecting the short-time neutral chemistry are fairly well established. The effects of photons on the neutral and negative-ion chemistry are uncertain. The neutral chemistry in the atmosphere is influenced by transport processes and reactions having long time constants. Since the AIRCHEM code is concerned with the short-time response of the atmosphere to ionizing radiation, transport processes and reactions having long time constants can be neglected without compromising the worth of the code. Good quantitative calculations cannot be made yet. In addition to the rate-coefficient requirements listed in this report, good models of the initial atmospheric minor constituents and of radiations from nuclear bursts must be obtained before truly quantitative calculations can be made of the response of the stratosphere and mesosphere to ionizing radiation.

ACKNOWLEDGEMENTS

The receipt of rate coefficients from F. C. Fehsenfeld, J. M. Heimerl, and J. A. Vanderhoff prior to publication is gratefully acknowledged. Discussions with members of the DNA Reaction Rate Handbook Committee and colleagues here at BRL have been stimulating and very helpful. I solicit new information on rate coefficients and comments regarding the proper set of reactions for the AIRCHEM code.

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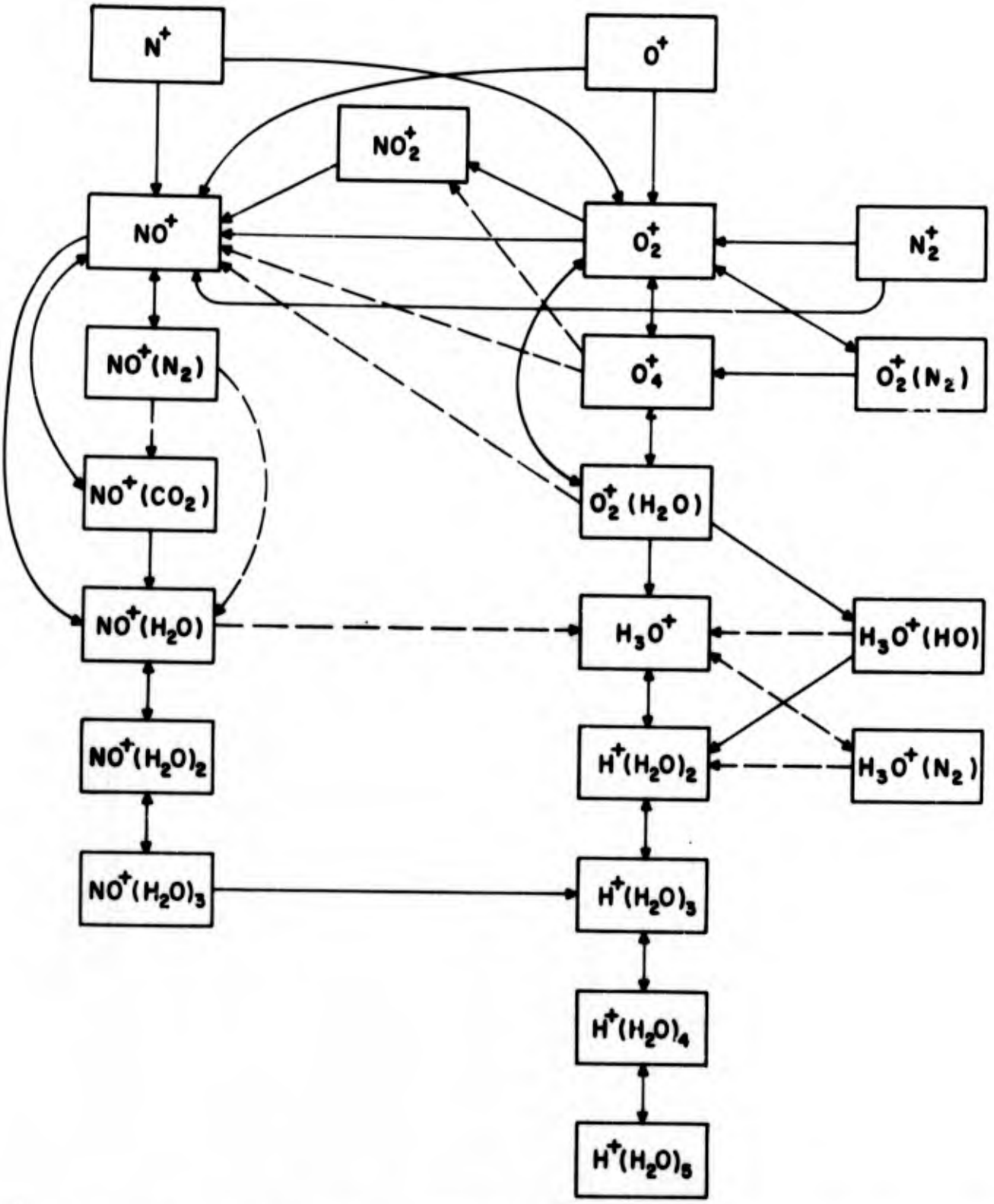

Figure 1. Schematic representation of the formation of positive ions in the stratosphere and mesosphere.

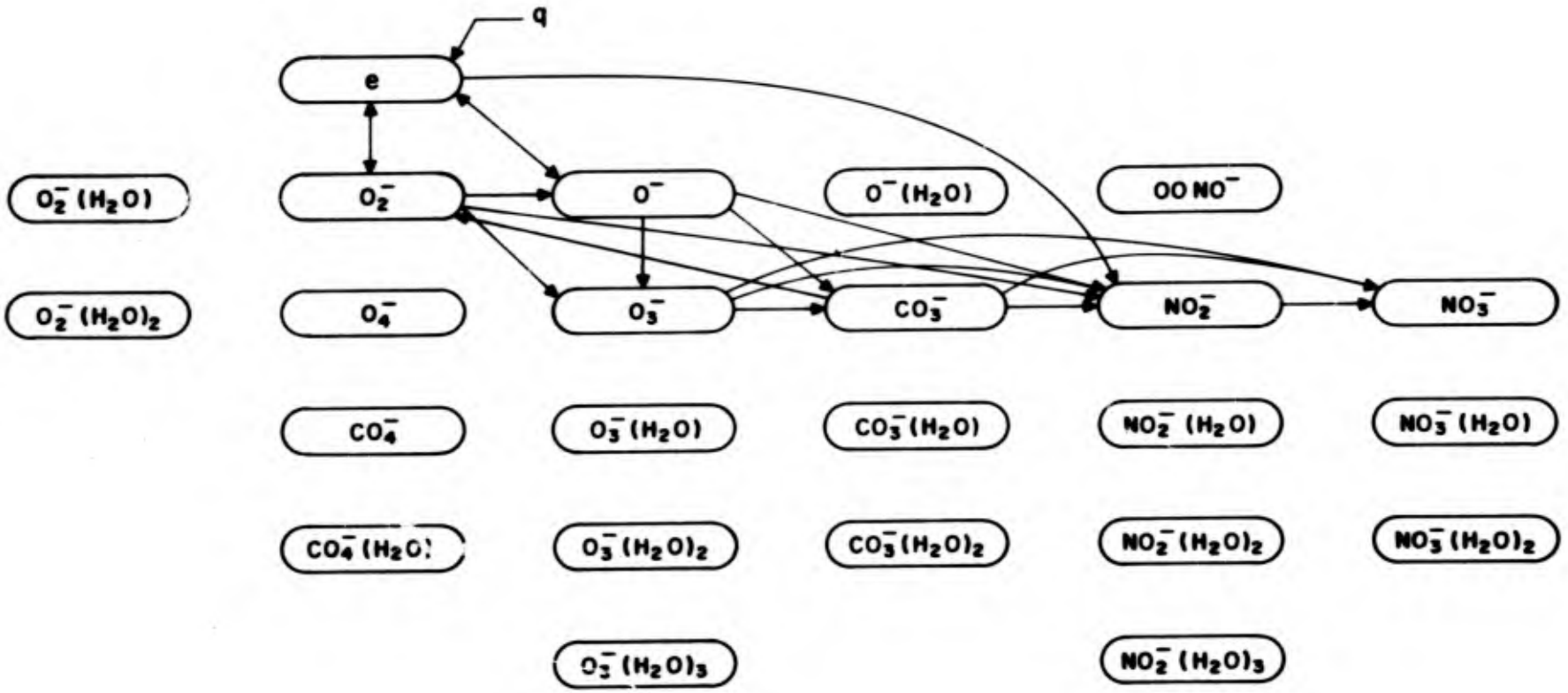

Figure 2. Schematic representation of the formation of negative ions in the stratosphere and mesosphere by reactions which do not involve cluster ions.

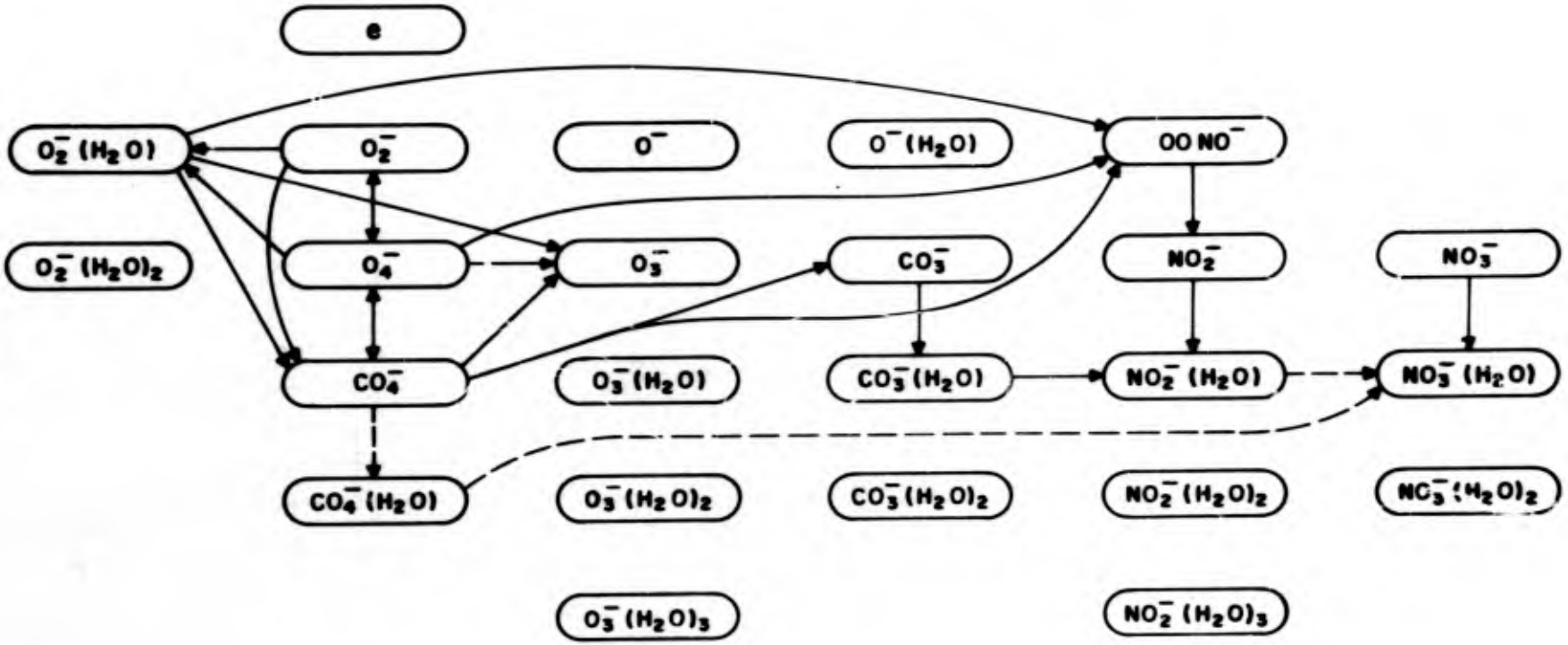

Figure 3. Schematic representation of the formation of negative ions in the stratosphere and mesosphere by reactions involving cluster ions as modeled in the AIRCHEM code.

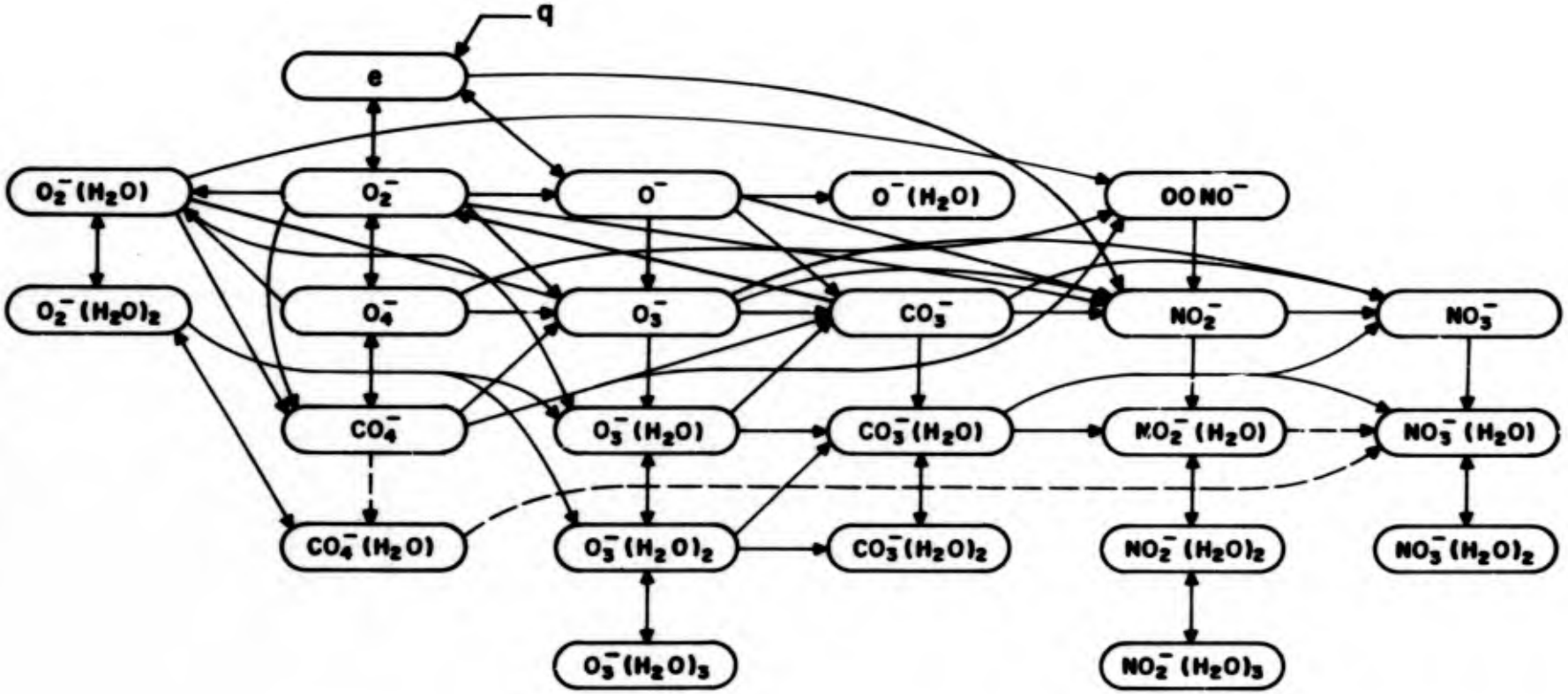

Figure 4. Schematic representation of the formation of negative ions in the stratosphere and mesosphere as suggested by laboratory measurements.

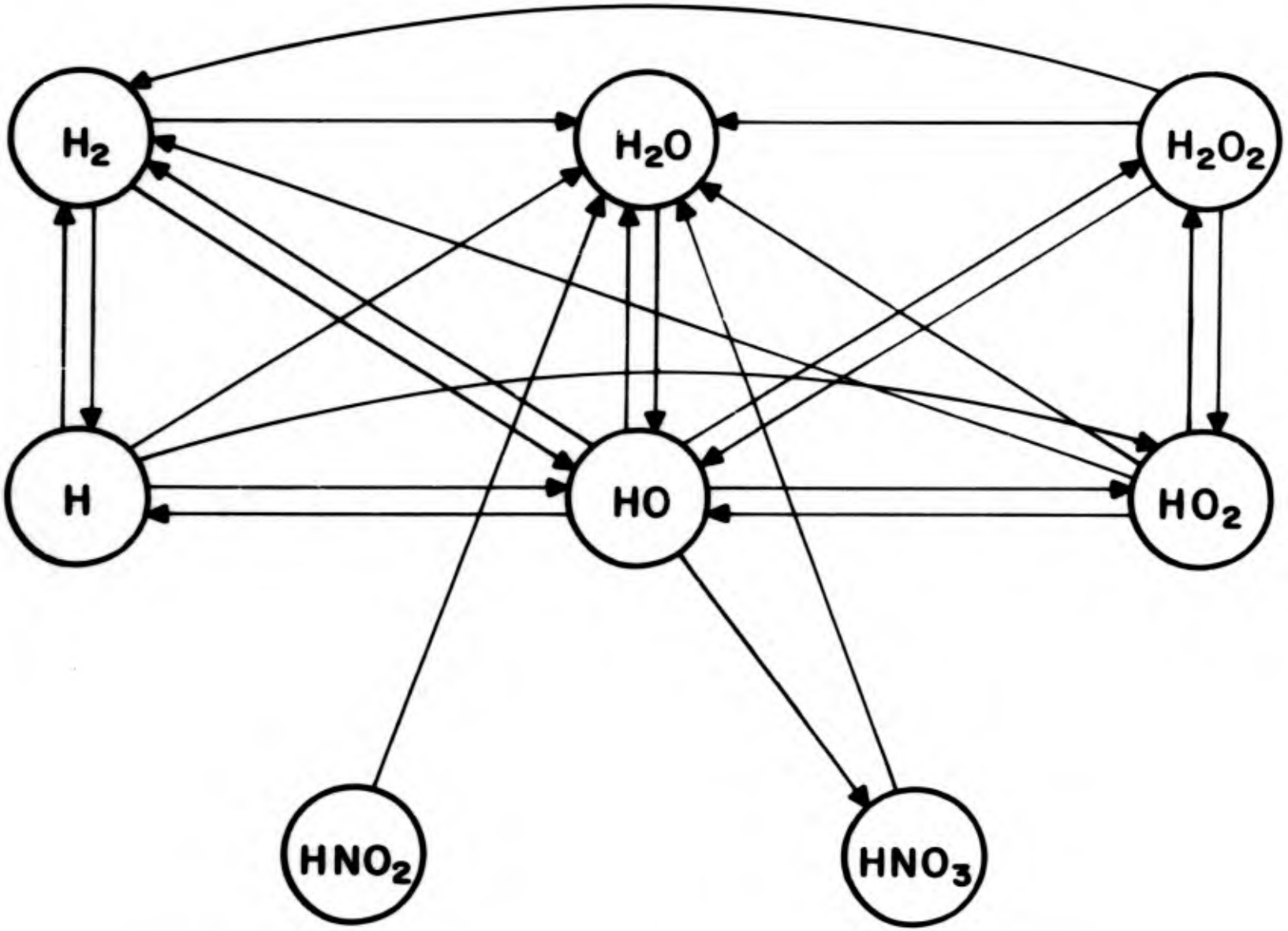

Figure 5. Schematic representation of the formation of odd hydrogen species by two-body and three-body neutral reactions in the stratosphere and mesosphere.

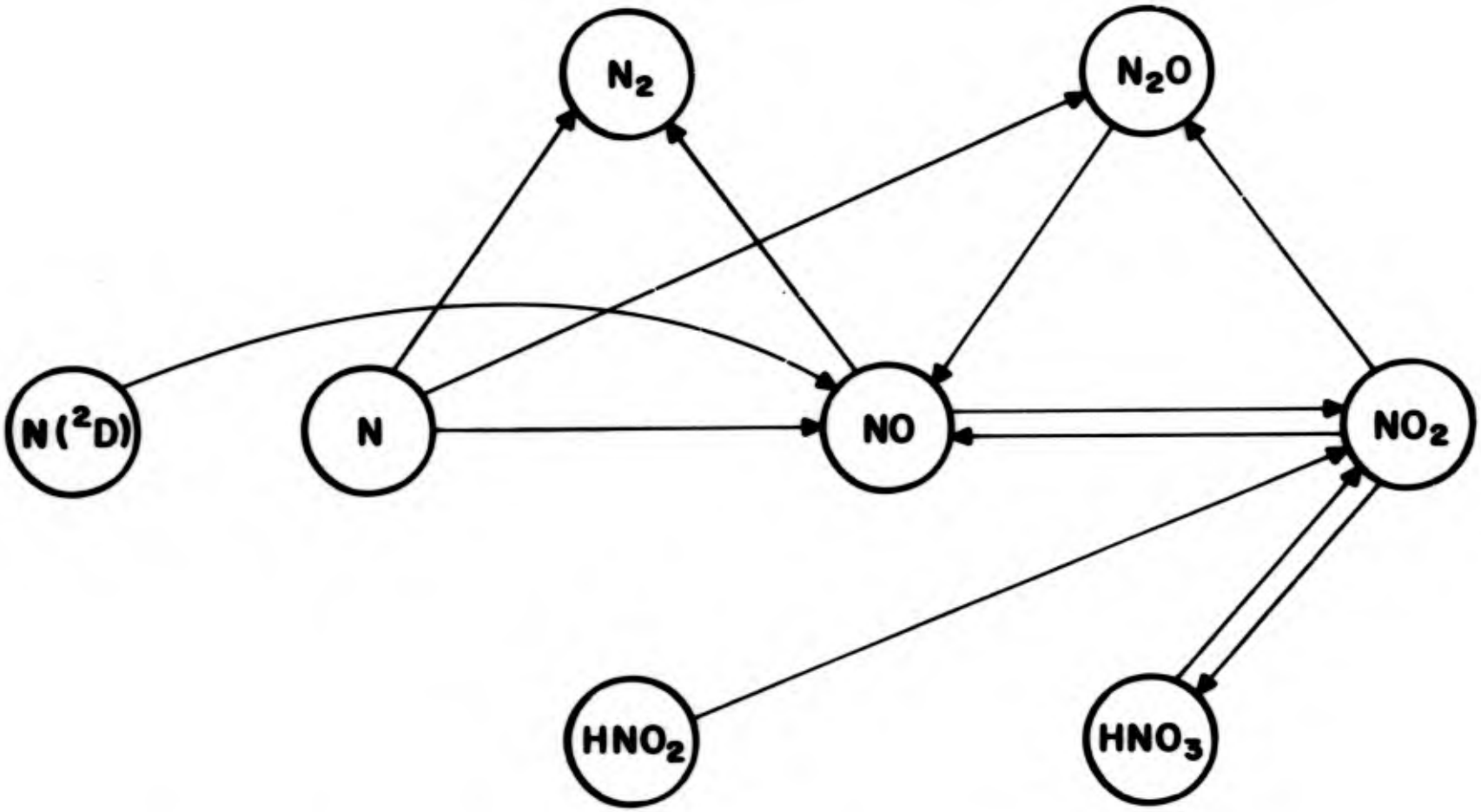

Figure 6. Schematic representation of the formation of odd nitrogen species by two-body and three-body neutral reactions in the stratosphere and mesosphere.

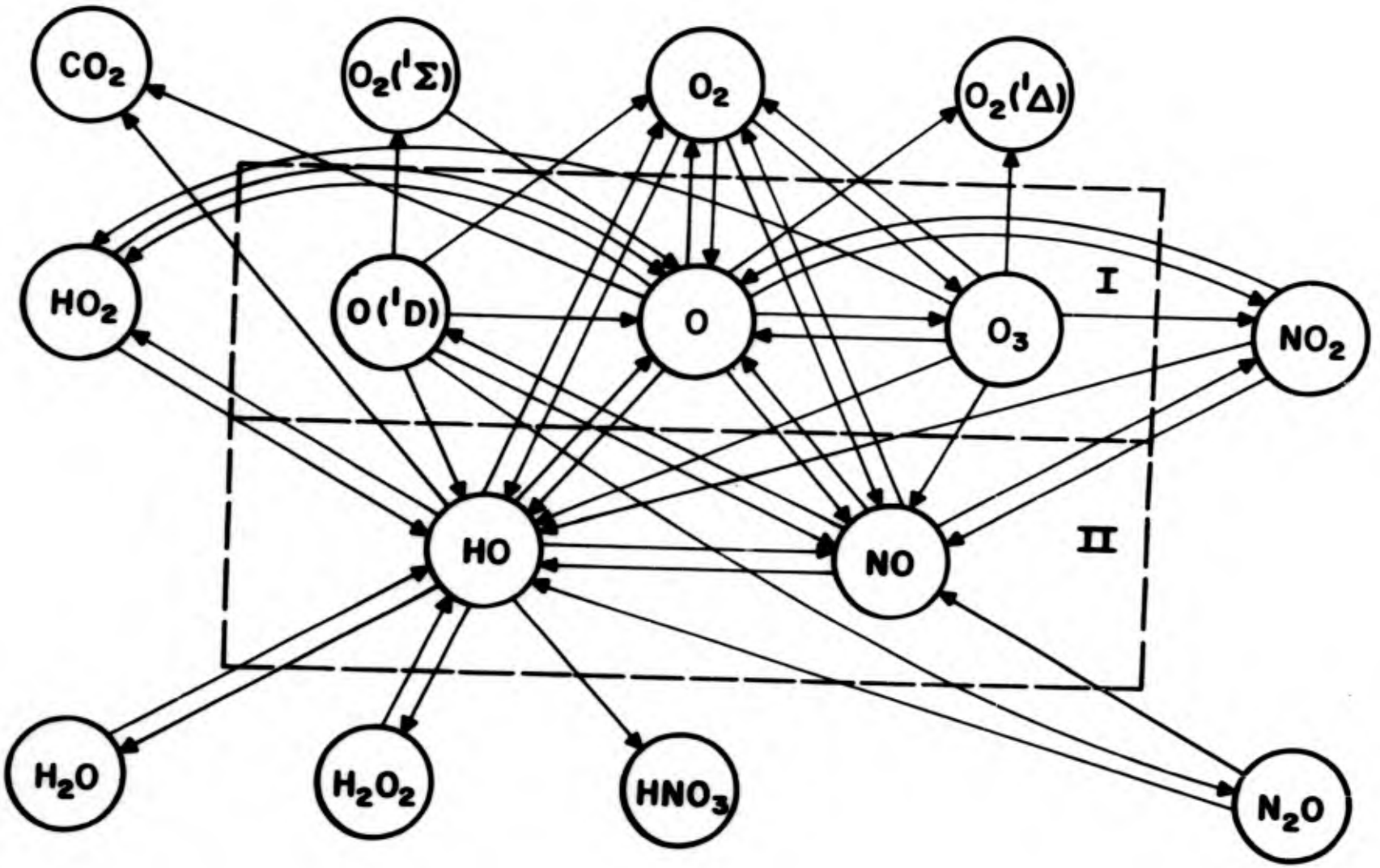

Figure 7. Schematic representation of the formation of odd oxygen species, HO and NO by two-body and three-body neutral reactions in the stratosphere and mesosphere.

TABLE I

Order of Ranking for Species

1. H_3O^+	24. $CO_3^-(H_2O)$	47. HO_2
2. $H_3O^+(HO)$	25. CO_4^-	48. H_2
3. $H_3O^+(N_2)$	26. $CO_4^-(H_2O)$	49. H_2O
4. $H^+(H_2O)_2$	27. NO_2^-	50. H_2O_2
5. $H^+(H_2O)_3$	28. $NO_2^-(H_2O)$	51. N
6. $H^+(H_2O)_4$	29. NO_3^-	52. NO
7. $H^+(H_2O)_5$	30. $NO_3^-(H_2O)$	53. NO_2
8. N^+	31. O^-	54. N_2
9. NO^+	32. O_2^-	55. N_2O
10. $NO^+(CO_2)$	33. $O_2^-(H_2O)$	56. O
11. $NO^+(H_2O)$	34. O_3^-	57. O_2
12. $NO^+(H_2O)_2$	35. O_4^-	58. O_3
13. $NO^+(H_2O)_3$	36. NO_3^{-*}	59. M
14. $NO^+(N_2)$	37. $N(^2D)$	
15. NO_2^+	38. $O(^1D)$	
16. N_2^+	39. $O_2(^1\Delta)$	
17. O^+	40. $O_2(^1\Sigma)$	
18. O_2^+	41. CO	
19. $O_2^+(H_2O)$	42. CO_2	
20. $O_2^+(N_2)$	43. H	
21. O_4^+	44. HNO_2	
22. e	45. HNO_3	
23. CO_3^-	46. HO	

TABLE II

Two- and Three-Body Positive-Ion Reactions Other Than Ionization, Ion-Electron Recombination, and Ion-Ion Recombination

$k = A(T/300)^{B}\exp(-C/T)$

Two-body reactions in units of cm^3 molecule^{-1} s^{-1} Three-body reactions in units of cm^6 molecule^{-1} s^{-1}

A. Reactions in AIRCHEM

	Reactions	Code Values A	B	C	Reference Values	References	Remarks
1a.	$H_3O^+ + H_2O + M \rightarrow H^+(H_2O)_2 + M$	3.4[-27]*	-2.0		$3.4[-27](T/300)^{-1^{+1}_{-2}}$	DNA 1948H, XVIII-21	
					3.7[-27]	Good et al., 1970a	307°K, M = O_2
					3.4[-27]	Good et al., 1970b	300°K, M = N_2
					~5 [-27]	Burt et al., 1970	300°K, M = H_2
					6 [-28]	Young et al., 1970	337°K, M = Ar
1b.	$H^+(H_2O)_2 + M \rightarrow H_3O^+ + H_2O + M$	8.0	-2.0	18000	$8(T/300)^{-1}\exp(-18000/T)$	DNA 1948H, XIX-4	
					~7 [-26]	Good et al., 1970b	300°K, M = N_2
2a.	$H_3O^+ + N_2 + M \rightarrow H_3O^+(N_2) + M$	1.4[-30]	-2.0				Estimated from map in Niles et al., 1972
2b.	$H_3O^+(N_2) + M \rightarrow H_3O^+ + N_2 + M$	1.2[- 8]	-2.0	2780			Estimated
3.	$H_3O^+(HO) + H_2O \rightarrow H^+(H_2O)_2 + HO$	1.4[- 9]			3.2[-9]	DNA 1948H, XIV-22	
					(1.4 ± 0.5)[-9]	Howard et al., 1972	296°K
4.	$H_3O^+(HO) + M \rightarrow H_3O^+ + HO + M$	1.0[- 1]	-2.0	11800	$1[-1](T/300)^{-1}\exp(-11800/T)$	DNA 1948H, XIX-3	Estimated
5.	$H_3O^+(N_2) + H_2O \rightarrow H^+(H_2O)_2 + N_2$	1.0[- 9]					Estimated
6a.	$H^+(H_2O)_2 + H_2O + M \rightarrow H^+(H_2O)_3 + M$	2.3[-27]	-2.0		$2.3[-27](T/300)^{-1^{+1}_{-2}}$	DNA 1948H, XVIII-22	
					2.0[-27]	Good et al., 1970a	307°K, M = O_2
					2.3[-27]	Good et al., 1970b	300°K, M = N_2
					~5 [-27]	Burt et al., 1970	300°K, M = H_2
					6 [-28]	Young et al., 1970	337°K, M = Ar
					1.7[-27]	Young & Falconer, 1972	310°K, M = O_2
6b.	$H^+(H_2O)_3 + M \rightarrow H^+(H_2O)_2 + H_2O + M$	1.0[- 1]	-2.0	11200	$1[-1](T/300)^{-1}\exp(-11200/T)$	DNA 1948H, XIX-5	
					1.4[-17]	Good et al., 1970a	307°K, M = O_2
					7 [-18]	Good et al., 1970b	300°K, M = N_2
					1 [-13]	Young et al., 1970	337°K, M = Ar

*Read 3.4[-27] as 3.4×10^{-27}.

Reactions	Code Values A	B	C	Reference Values	References	Remarks
7a. $H^+(H_2O)_3 + H_2O + M \rightarrow H^+(H_2O)_4 + M$	2.4[-27]	-2.0		$2.4[-27](T/300)^{-1^{+1}_{-2}}$	DNA 1948H, XVIII-23	
				2 [-27]	Good et al., 1970a	307°K, M = O_2
				2.4[-27]	Good et al., 1970b	300°K, M = N_2
				(3.5 ± 0.8)[-27]	Puckett & Teague, 1971	296°K, M = NO
				1.0[-27]	Young & Falconer, 1972	310°K, M = O_2
7b. $H^+(H_2O)_4 + M \rightarrow H^+(H_2O)_3 + H_2O + M$	1.0[- 1]	-2.0	8600	$1[-1](T/300)^{-1}\exp(-8600/T)$	DNA 1948H, XIX-6	
				4[-14]	Good et al., 1970a	307°K, M = O_2
				4[-14]	Good et al., 1970b	300°K, M = N_2
				(1.3 ± 0.4)[-14]	Puckett & Teague, 1971	296°K, M = NO
8a. $H^+(H_2O)_4 + H_2O + M \rightarrow H^+(H_2O)_5 + M$	8.8[-28]	-2.0		$8.8[-28](T/300)^{-1^{+1}_{-2}}$	DNA 1948H, XVIII-24	
				9 [-28]	Good et al., 1970a	307°K, M = O_2
				~2 [-29]	Young & Falconer, 1972	310°K, M = O_2
8b. $H^+(H_2O)_5 + M \rightarrow H^+(H_2O)_4 + H_2O + M$	3.0[- 3]	-2.0	6000	$3[-3](T/300)^{-1}\exp(-6000/T)$	DNA 1948H, XIX-7	
				6 [-12]	Good et al., 1970a	307°K, M = O_2
9a. $N^+ + O_2 \rightarrow O_2^+ + N$	3.0[-10]			(3.0 ± 1.5)[-10]	DNA 1948H, XIII-10	
				2.5[-10]	Johnsen et al., 1970	
				6 [-10]	Dunkin et al., 1968	Total loss of N^+
				4.5[-10]	Warneck, 1967a	
				4 [-10]	Aquilanti & Volpi, 1966	
				5 [-10]	Stebbings et al., 1966	Extrapolated to 300°K
9b. $N^+ + O_2 \rightarrow NO^+ + O$	3.0[-10]			3 [-10]	DNA 1948H, XIV-5	
				2.5[-10]	Johnsen et al., 1970	
				6 [-10]	Dunkin et al., 1968	Total loss of N^+
				1.6[-10]	Warneck, 1967a	
				3 [-10]	Aquilanti & Volpi, 1966	
				5 [-10]	Stebbings et al., 1966	Extrapolated to 300°K
				1 [-10]	Galli et al., 1963	
				5 [-10]	Fite et al., 1962	

	Reactions	Code Values A	B	C	Reference Values	References	Remarks
10a.	$NO^+ + CO_2 + M \rightarrow NO^+(CO_2) + M$	2.0[-29]	-2.0		$2\,[-29](T/300)^{-1^{+1}_{-2}}$	DNA 1948H, XVIII-20	
					1.0[-29]	Dunkin et al., 1971b	200°K, M = He
					3 [-29]	"	200°K, M = N_2
					2 [-29]	Heimerl & Puckett, 1971	300°K, M = CO_2
					(2.4 ± 0.7)[-29]	Heimerl & Vanderhoff, 1973	
10b.	$NO^+(CO_2) + M \rightarrow NO^+ + CO_2 + M$	1.0[- 8]	-2.0	5000			Estimated
11.	$NO^+ + H_2O + M \rightarrow NO^+(H_2O) + M$	1.5[-28]	-2.0		$1.5[-28](T/300)^{-1^{+1}_{-2}}$	DNA 1948H, XVIII-17	
					(1.6 ± 0.3)[-28]	Puckett & Teague, 1971	296°K, M = NO
					(3.2 ± 0.3)[-29]	Howard et al., 1971	296°K, M = He
					(9 ± 2)[-29]	"	296°K, M = Ar
					(9 ± 1)[-29]	"	296°K, M = O_2
					(1.4 ± 1)[-28]	"	296°K, M = N_2
					3.6[-29]	Fehsenfeld et al., 1971a	300°K, M = He
					7.8[-29]	"	300°K, M = Ar
					1.6[-28]	"	300°K, M = N_2
					(1.3 ± 0.3)[-28]	McAdams & Bone, 1972	300°K, M = NO, H_2O
12a.	$NO^+ + N_2 + M \rightarrow NO^+(N_2) + M$	2.0[-31]	-2.0		(2.0 ± 0.6)[-31]	Heimerl & Vanderhoff, 1973	298°K, M = N_2
12b.	$NO^+(N_2) + M \rightarrow NO^+ + N_2 + M$	1.2[- 8]	-2.0	2780	<3 [-11]	Heimerl & Vanderhoff, 1973	298°K, M = N_2
13.	$NO^+(CO_2) + H_2O \rightarrow NO^+(H_2O) + CO_2$	1.0[- 9]			1 [- 9]	DNA 1948H, XIV-26	
					~1 [- 9]	Dunkin et al., 1971b	
14.	$NO^+(H_2O) + HO \rightarrow H_3O^+ + NO_2$	1.0[- 9]					Estimated
15.	$NO^+(H_2O) + HO_2 \rightarrow H_3O^+ + NO + O_2$	1.0[- 9]					Estimated

	Reactions	Code Values A	B	C	Reference Values	References	Remarks
16a.	$NO^+(H_2O) + H_2O + M \rightarrow NO^+(H_2O)_2 + M$	1.1[-27]	-2.0		$1.1[-27](T/300)^{-1^{+1}_{-2}}$	DNA 1948H, XVIII-18	
					(1.1 ± 0.3)[-27]	Puckett & Teague, 1971	295°K, M = NO
					(3 ± 0.7)[-28]	Howard et al., 1971	296°K, M = He
					(8 ± 2)[-28]	"	296°K, M = O_2
					(1.0 ± 0.4)[-27]	"	296°K, M = Ar
					(1.2 ± 0.2)[-27]	"	296°K, M = N_2
					3 [-28]	Fehsenfeld et al., 1971a	300°K, M = He
					8 [-28]	"	300°K, M = Ar
					1 [-27]	"	300°K, M = N_2
					(1.2 ± 0.3)[-27]	McAdams & Bone, 1972	300°K, M = NO H_2O
16b.	$NO^+(H_2O)_2 + M \rightarrow NO^+(H_2O) + H_2O + M$	1.0[- 4]	-2.0	7000	(1.4 ± 0.4)[-14]	Puckett & Teague, 1971	296°K, M = NO
					(3 ± 1)[-15]	Howard et al., 1971	296°K, M = He
					(1.3 ± 0.5)[-14]	"	296°K, M = Ar
					(1.0 ± 0.3)[-14]	"	296°K, M = O_2
					(1.7 ± 0.5)[-14]	"	296°K, M = N_2
					<1 [-13]	Fehsenfeld et al., 1971a	300°K
					<2 [-13]	McAdams & Bone, 1972	300°K, M = NO H_2O
17a.	$NO^+(H_2O)_2 + H_2O + M \rightarrow NO^+(H_2O)_3 + M$	1.6[-27]	-2.0		$1.6[-27](T/300)^{-1^{+1}_{-2}}$	DNA 1948H, XVIII-19	
					(1.9 ± 0.6)[-27]	Puckett & Teague, 1971	296°K, M = NO
					(3.3 ± 0.3)[-28]	Howard et al., 1971	296°K, M = He
					(9 ± 2)[-28]	"	296°K, M = O_2
					(1.2 ± 0.4)[-27]	"	296°K, M = Ar
					(1.4 ± 0.2)[-27]	"	296°K, M = N_2
					4 [-28]	Fehsenfeld et al., 1971a	300°K, M = He
					1.5[-27]	"	300°K, M = Ar
					2 [-27]	"	300°K, M = N_2
					(3.6 ± 1.3)[-27]	McAdams & Bone, 1972	300°K, M = NO H_2O

	Reactions	Code Values A	B	C	Reference Value	References	Remarks
17b.	$NO^+(H_2O)_3 + M \rightarrow NO^+(H_2O)_2 + H_2O + M$	2.0[- 2]	-2.0	7000	(1.9 ± 0.6)[-12]	Puckett & Teague, 1971	296°K, M = NO
					(3.0 ± 0.5)[-13]	Howard et al., 1971	296°K, M = He
					(8 ± 3)[-13]	"	296°K, M = O_2
					(1.1 ± 0.5)[-12]	"	296°K, M = Ar
					(1.4 ± 0.25)[-12]	"	296°K, M = N_2
					2.7[-13]	Fehsenfeld et al., 1971a	300°K, M = He
					1.0[-12]	"	300°K, M = Ar
					1.3[-12]	"	300°K, M = N_2
					<4 [-12]	McAdams & Bone, 1972	300°K, M = NO H_2O
18.	$NO^+(H_2O)_3 + H_2O \rightarrow H^+(H_2O)_3 + HNO_2$	7.0[-11]			(7 ± 2)[-11]	DNA 1948H, XIV-25	
					(7^{+2}_{-1}) [-11]	Howard et al., 1971	300°K, M = He, Ar, O_2, N_2
					8 [-11]	Fehsenfeld et al., 1971a	300°K, M = He, Ar, N_2
					(7 ± 2)[-11]	Puckett & Teague, 1971	296°K, M = NO
19.	$NO^+(N_2) + CO_2 \rightarrow NO^+(CO_2) + N_2$	1.0[- 9]					Estimated
20.	$NO^+(N_2) + H_2O \rightarrow NO^+(H_2O) + N_2$	1.0[- 9]					Estimated
21.	$NO_2^+ + NO \rightarrow NO^+ + NO_2$	2.9[-10]			2.9[-10]	DNA 1948H, XIII-26	
					2.9[-10]	Fehsenfeld et al., 1969	
22a.	$N_2^+ + O \rightarrow NO^+ + N(^2D)$	7.0[-11]					1/2 of total loss rate
22b.	$N_2^+ + O \rightarrow NO^+ + N$	7.0[-11]			(1.4 ± 0.8)[-10]	DNA 1948H, XIV-12	Total loss rate
					$(1.4^{+1.4}_{-0.7})$[-10]	Fehsenfeld et al., 1970	
					(1.3 ± 0.7)[-10]	Neynaber et al., 1973	

	Reactions	Code Values A	B	C	Reference Value	References	Remarks
23.	$N_2^+ + O_2 \rightarrow O_2^+ + N_2$	5.0[-11]	-0.5		$(5 \pm 1)[-11](T/300^{-0.5}$	DNA 1948H, XIII-20	
					6 [-11]	Johnsen et al., 1970	Decreases with T
					4.7[-11]	Dunkin et al., 1968	Decreases with T
					7.8[-11]	Golden et al., 1968	Decreases with E/P
					1.1[-10]	Warneck, 1967a,b	
					6.5[-11]	Aquilanti & Volpi, 1966	
24.	$O^+ + N_2 \rightarrow NO^+ + N$	1.2[-12]	-0.5		$1.2[-12](T/300)^{-0.5}$	DNA 1948H, XIV-1	
					1.2[-12]	Dunkin et al., 1968	300°K, Decreases with T
					~1 [-12]	Schmeltekopf et al., 1967	Depends on vibrational level of N_2
					3.72[-12]	Nakshbandi & Hasted, 1967	
					7 [-12]	Bohme et al., 1967	0.07 eV ion energy
					4.6[-12]	Warneck, 1967a	
					(2.4 ± 0.4)[-12]	Copsey et al., 1966	
					(5 ± 3)[-12]	Aquilanti & Volpi, 1966	
					3 [-12]	Stebbings et al., 1966	Extrapolated to 300°K
25.	$O^+ + N_2 + M \rightarrow NO^+ + N + M$	1.6[-29]	-2.0		$2.0[-28](T/300)^{-1^{+1}_{-2}}$	DNA 1948H, XVIII-3	Error in handbook
					5.4[-29]	Bohme et al., 1969	82°K, M = He
26.	$O^+ + O_2 \rightarrow O_2^+ + O$	2.0[-11]	-0.5		$2[-11](T/300)^{-0.5}$	DNA 1948H, XIII-2	
					2[-11]	Dunkin et al., 1971a	
					$(3.4 \pm 0.5)[-10]T^{-(0.48 \pm 0.05)}$	Smith & Fouracre, 1968	
					1.69[-11]	Nakshbandi & Hasted, 1967	300°K
					2 [-11]	Bohme et al., 1967	300°K
					2 [-11]	Warneck, 1967a	300°K

	Reactions	Code Values A	B	C	Reference Value	References	Remarks
27.	$O_2^+ + H_2O + M \rightarrow O_2^+(H_2O) + M$	2.8[-28]	-2.0		$1.9[-28](T/300)^{-1^{+1}_{-2}}$	DNA 1948H, XVIII-15	
					9 [-29]	Fehsenfeld et al., 1971b	300°K, M = He
					2.0[-28]	"	300°K, M = Ar
					2.8[-28]	"	300°K, M = N_2
					8.7[-29]	Howard et al., 1972	296°K, M = He
					1.9[-28]	"	296°K, M = O_2
					1.3[-28]	Young & Falconer, 1972	310°K, M = Ar
					2.9[-28]	"	310°K, M = O_2
28.	$O_2^+ + N \rightarrow NO^+ + O$	1.8[-10]			(1.8 ± 0.6)[-10]	DNA 1948H, XIV-7	
					$(1.8^{+0.2}_{-0.9})$[-10]	Goldan et al., 1966	
29.	$O_2^+ + NO \rightarrow NO^+ + O_2$	6.3[-10]			(6.3 ± 2.4)[-10]	DNA 1948H, XIII-15	
					(6.3 ± 2.1)[-10]	Fehsenfeld et al., 1970	
					3 [-10]	Johnsen et al., 1970	
					7.7[-10]	Warneck, 1967a	
30.	$O_2^+ + NO_2 \rightarrow NO_2^+ + O_2$	6.6[-10]			(6.6 ± 2.2)[-10]	Fehsenfeld et al., 1973	
31.	$O_2^+ + N_2 \rightarrow NO^+ + NO$	1.0[-16]			$1\ [-16^{+1}_{-3}]$	DNA 1948H, XIV-8	
					<3.0[-15]	Warneck, 1967a	
					<2 [-16]	Shahin, 1967	
					<1.0[-15]	Ferguson et al., 1965	300°-600°K
32a.	$O_2^+ + N_2 + M \rightarrow O_2^+(N_2) + M$	8.0[-31]	-2.0		$2.9[-29](T/300)^{-1^{+1}_{-2}}$	DNA 1948H, XVIII-14	
					(8 ± 4)[-31]	Howard et al., 1972	296°K, M = N_2
					1.9[-29]	Adams et al., 1970	200°K, M = He
32b.	$O_2^+(N_2) + M \rightarrow O_2^+ + N_2 + M$	-			(2.0 ± 1.3)[-11]	Howard et al., 1972	296°K, M = N_2

Reactions	Code Values A	B	C	Reference Value	References	Remarks
33a. $O_2^+ + O_2 + M \rightarrow O_4^+ + M$	2.8[-30]	-2.0		$2.7[-30](T/300)^{-1^{+1}_{-2}}$	DNA 1948H, XVIII-13	
				3.1[-29]	Bohme et al., 1968	80°K, M = He
				2.8[-30]	Durden et al., 1969	298°K, M = O_2
				2.4[-30]	Adams et al., 1970	200°K, M = He
				1.5[-30]	Young & Falconer, 1972	310°K, M = O_2
				(2.5 ± 0.5)[-30]	Howard et al., 1972	296°K, M = O_2
33b. $O_4^+ + M \rightarrow O_2^+ + O_2 + M$	5.0[- 7]	-2.0	5000	$5[-7](T/300^{-1})\exp(-5000/T)$	DNA 1948H, XIX-1	
				2.8[-13]	Durden et al., 1969	298°K, M = O_2
				<3 [-17]	Adams et al., 1970	200°K, M = He
				(1.8 ± 0.8)[-13]	Howard et al., 1972	296°K, M = O_2
34a. $O_2^+(H_2O) + H_2O \rightarrow H_3O^+ + HO + O_2$	2.0[-10]			$3[-10]\exp(-3000/T)$	DNA 1948H, XIV-21a	Exponent in error
				2[-10]	Howard et al., 1972	
				≤3[-10]	Fehsenfeld et al., 1971b	295°K
				3[-10]	Good et al., 1970a	
34b. $O_2^+(H_2O) + H_2O \rightarrow H_3O^+(HO) + O_2$	1.0[- 9]			1.9[-9]	DNA 1948H, XIV-21b	
				1.0[-9]	Howard et al., 1972	
				1 [-9]	Young & Falconer, 1972	
				1.9[-9]	Fehsenfeld et al., 1971b	
				9[-10]	Good et al., 1970a	
35. $O_2^+(H_2O) + NO \rightarrow NO^+ + H_2O + O_2$	1.0[-10]			1[-10]	DNA 1948H, XIV-28	Estimated
36. $O_2^+(H_2O) + O_2(^1\Delta) \rightarrow O_2^+ + H_2O + O_2$	1.0[-10]					Estimated
37. $O_2^+(N_2) + O_2 \rightarrow O_4^+ + N_2$	1.0[- 9]			5[-11]	DNA 1948H, XIV-19	Minimum value at 80°K
				>5.0[-11]	Adams et al., 1970	80°K
38a. $O_4^+ + H_2O \rightarrow O_2^+(H_2O) + O_2$	1.5[- 9]			2.2[- 9]	DNA 1948H, XIV-20	
				(1.5 ± 0.5)[-9]	Howard et al., 1972	
				2.2[- 9]	Fehsenfeld et al., 1971b	
				1.3[- 9]	Good et al., 1970a	

	Reactions	Code Values A	B	C	Reference Values	References	Remarks
38b.	$O_2^+(H_2O) + O_2 \rightarrow O_4^+ + H_2O$	2.0[-10]		2300	2[-10]exp(-2300/T)	DNA 1948H, XIV-31	Estimated
39.	$O_4^+ + NO \rightarrow NO^+ + 2O_2$	5.0[-10]			5[-10]	DNA 1948H, XIV-30	Estimated
40.	$O_4^+ + NO_2 \rightarrow NO_2^+ + 2O_2$	5.0[-10]					Estimated
41.	$O_4^+ + O \rightarrow O_2^+ + O_3$	3.0[-10]			(3 ± 2)[-10]	DNA 1948H, XIV-29	
					(3 ± 2)[-10]	Fehsenfeld & Ferguson, 1972	

B. Reactions Omitted from AIRCHEM

1.	$C^+ + CO_2 \rightarrow CO^+ + CO$				(1.8 ± 0.6)[- 9]	DNA 1948H, XIV-33	C^+ and CO^+ not in AIRCHEM
2.	$C^+ + O_2 \rightarrow CO^+ + O$				(1.1 ± 0.3)[- 9]	DNA 1948H, XIV-32	C^+ and CO^+ not in AIRCHEM
3.	$CO^+ + NO \rightarrow NO^+ + CO$				3.3[-10]	DNA 1948H, XIII-32	CO^+ not in AIRCHEM
4.	$CO^+ + O \rightarrow O^+ + CO$				1.4[-10]	DNA 1948H, XIII-31	CO^+ not in AIRCHEM
5.	$CO_2^+ + NO \rightarrow NO^+ + CO_2$				1.2[-10]	DNA 1948H, XIII-35	CO_2^+ not in AIRCHEM
6a.	$CO_2^+ + O \rightarrow O^+ + CO_2$				1 [-10]	DNA 1948H, XIII-33	CO_2^+ not in AIRCHEM
6b.	$CO_2^+ + O \rightarrow O_2^+ + CO$				1.6[-10]	DNA 1948H, XIV-34	CO_2^+ not in AIRCHEM
7.	$CO_2^+ + O_2 \rightarrow O_2^+ + CO_2$				5 [-11]	DNA 1948H, XIII-34	CO_2^+ not in AIRCHEM
8.	$H^+ + NO \rightarrow NO^+ + H$				1.9[- 9]	DNA 1948H, XIII-28	H^+ not in AIRCHEM
9.	$H^+ + O \rightarrow O^+ + H$				3.8[-10]	DNA 1948H, XIII-27	H^+ not in AIRCHEM
					2.3[-10]	Neynaber et al., 1973	2 eV
10.	$HO^+ + O_2 \rightarrow O_2^+ + HO$				2 [-10]	DNA 1948H, XIII-29	HO^+ not in AIRCHEM
11.	$H_2O^+ + H_2O \rightarrow H_3O^+ + HO$				1.8[- 9]	DNA 1948H, XIV-23	H_2O^+ not in AIRCHEM
12.	$H_2O^+ + O_2 \rightarrow O_2^+ + H_2O$				2 [-10]	DNA 1948H, XIII-30	H_2O^+ not in AIRCHEM
13.	$N^+ + CO \rightarrow CO^+ + N$				(9 ± 3)[-10]	DNA 1948H, XIII-13	CO^+ not in AIRCHEM
14.	$N^+ + CO_2 \rightarrow CO_2^+ + N$				(1.3 ± 0.4)[- 9]	DNA 1948H, XIII-14	CO_2^+ not in AIRCHEM
15.	$N^+ + H_2 \rightarrow HN^+ + H$				5.6[-10]	DNA 1948H, XIV-6	HN^+ not in AIRCHEM
16.	$N^+ + H_2O \rightarrow H_2O^+ + N$				2.6[- 9]	DNA 1948H, XIII-12	H_2O^+ not in AIRCHEM

	Reactions	Reference Values	References	Remarks
17.	$N^+ + N + M \rightarrow N_2^+ + M$	$1[-29\pm2](T/300)^{-1^{+1}_{-2}}$	DNA 1948H, XVIII-7	Estimated
18a.	$N^+ + NO \rightarrow NO^+ + N$	$(8.0 \pm 2.4)[-10]$	DNA 1948H, XIII-11	Removed from AIRCHEM as unimportant
		(8^{+1}_{-4}) [-10]	Goldan et al., 1966	300°K
18b.	$N^+ + NO \rightarrow N_2^+ + O$			Removed from AIRCHEM as unimportant
19.	$N^+ + N_2 + M \rightarrow N_3^+ + M$	$(2\pm1)[-29](T/300)^{-1^{+1}_{-2}}$	DNA 1948H, XVIII-11	N_3^+ not in AIRCHEM
		8.6[-30]	Bohme et al., 1969	280°K, M = He
		7.2[-29]	"	82°K, M = He
		$(1.8 \pm 0.2)[-29]$	Moseley et al., 1969	Thermal energy
20.	$N^+ + N_2O \rightarrow NO^+ + N_2$			Removed from AIRCHEM as unimportant
21.	$N^+ + O \rightarrow O^+ + N$	1 [-12]	DNA 1948H, XIII-9	Estimated; removed from AIRCHEM as unimportant
22.	$N^+ + O + M \rightarrow NO^+ + M$	$1[-29\pm2](T/300)^{-1^{+1}_{-2}}$	DNA 1948H, XVIII-6	Estimated
23.	$N^+ + O_2 \rightarrow O^+ + NO$			Removed from AIRCHEM as unimportant
24.	$NO^+ + N + M \rightarrow N_2O^+ + M$	$1[-29\pm2](T/300)^{-1^{+1}_{-2}}$	DNA 1948H, XVIII-12	N_2O^+ not in AIRCHEM
25.	$NO^+ + Na \rightarrow Na^+ + NO$	7.0[-11]	DNA 1948H, XIII-25	Na^+ and Na not in AIRCHEM
26a.	$NO^+ + NO + M \rightarrow NO^+(NO) + M$	$5.0[-30](T/300)^{-1^{+1}_{-2}}$	DNA 1948H, XVIII-16	$NO^+(NO)$ not in AIRCHEM
26b.	$NO^+(NO) + M \rightarrow NO^+ + NO + M$	$1\ [-\ 5](T/300)^{-1}\exp(-7000/T)$	DNA 1948H, XIX-2	$NO^+(NO)$ not in AIRCHEM
27.	$NO^+ + O + M \rightarrow NO_2^+ + M$	$5[-29\pm2](T/300)^{-1^{+1}_{-2}}$	DNA 1948H, XVIII-10	Estimated; removed from AIRCHEM as unimportant
28.	$NO^+ + O_3 \rightarrow NO_2^+ + O_2$	$1[-13\pm2]$	DNA 1948H, XIV-16	Estimated
29.	$NO^+(H_2O) + H \rightarrow H_3O^+ + NO$	<1 [-11]	Fehsenfeld & Ferguson, 1972	Removed from AIRCHEM as unimportant
30a.	$NO^+(NO) + H_2O \rightarrow NO^+(H_2O) + NO$	$(1.4 \pm 0.3)[-9]$	DNA 1948H, XIV-24	$NO^+(NO)$ not in AIRCHEM
30b.	$NO^+(H_2O) + NO \rightarrow NO^+(NO) + H_2O$	$2[-10]\exp(-2300/T)$	DNA 1948H, XIV-31	$NO^+(NO)$ not in AIRCHEM
31.	$N_2^+ + CO_2 \rightarrow CO_2^+ + N_2$	(9 ± 3) [-10]	DNA 1948H, XIII-23	CO_2^+ not in AIRCHEM
32.	$N_2^+ + H_2 \rightarrow HN_2^+ + H$	1.7[-9]	DNA 1948H, XIV-14	HN_2^+ not in AIRCHEM
33a.	$N_2^+ + H_2O \rightarrow H_2O^+ + N_2$	2.2[-9]	DNA 1948H, XIII-22	Total rate; H_2O^+ not in AIRCHEM

	Reactions	Reference Values	References	Remarks
33b.	$N_2^+ + H_2O \rightarrow HN_2^+ + HO$	2.2 [- 9]	DNA 1948H, XIV-15	Total rate; HN_2^+ not in AIRCHEM
34.	$N_2^+ + N \rightarrow N^+ + N_2$	<1 [-11]	DNA 1948H, XIII-19	Removed from AIRCHEM as unimportant
		<1.0 [-11]	Ferguson et al., 1965	Not observed
35.	$N_2^+ + N + M \rightarrow N_3^+ + M$	$1[-29 \pm 2](T/300)^{-1^{+1}_{-2}}$	DNA 1948H, XVIII-8	Estimated; N_3^+ not in AIRCHEM
36.	$N_2^+ + Na \rightarrow Na^+ + N_2$	5.8 [-10]	DNA 1948H, XIII-24	Na^+ and Na not in AIRCHEM
37.	$N_2^+ + NO \rightarrow NO^+ + N_2$	(3.3 ± 1.5)[-10]	DNA 1948H, XIII-21	Removed from AIRCHEM as unimportant
		8.1 [-10]	Neynaber et al., 1971	Extrapolated to 300°K
		(3.1 ± 1.1)[-10]	Fehsenfeld et al., 1970	300°K
		4.8 [-10]	Warneck, 1967a	
38.	$N_2^+ + NO_2 \rightarrow NO_2^+ + N_2$			Removed from AIRCHEM as unimportant
39.	$N_2^+ + N_2 \rightarrow N_3^+ + N$	(2.76 ± 0.06)[-12]	Jaffe et al., 1973	Thermal energy; N_3^+ not in AIRCHEM
40a.	$N_2^+ + N_2 + M \rightarrow N_4^+ + M$	$5.0[-29](T/300)^{-1^{+\frac{1}{2}}_{-2}}$	DNA 1948H, XVIII-9	$M = N_2$; N_4^+ not in AIRCHEM
		(5.3 ± 0.3)[-30]	Mark & Oskam, 1971	300°K, M = He
		8 [-29]	Good et al., 1970b	300°K, $M = N_2$
		$(5.0^{+0.9}_{-0.6})[-29]$	Moseley et al., 1969	Thermal energy; $M = N_2$
		1.2[-28]	Bohme et al., 1969	80°K, M = He
		1.9[-29]	"	280°K, M = He
		$(7^{+7}_{-3.5})[-29]$	McKnight et al., 1967	$E/N = 5 \times 10^{-16}$ V cm^2; $M = N_2$
		8.5[-29]	Warneck, 1967b	300°K, $M = N_2$
40b.	$N_4^+ + M \rightarrow N_2^+ + N_2 + M$	3 [-14]	McKnight et al., 1967	At lowest E/N; N_4^+ not in AIRCHEM
41a.	$N_2^+ + N_2O \rightarrow N_2O^+ + N_2$	(5.0 ± 0.3)[-10]	Ryan, 1972	0.1 eV; N_2O^+ not in AIRCHEM
41b.	$N_2^+ + N_2O \rightarrow NO^+ + N + N_2$	(5.7 ± 0.3)[-11]	Ryan, 1972	0.1 eV
42.	$N_2^+ + O \rightarrow O^+ + N_2$	6 [-12]	DNA 1948H, XIII-18	Removed from AIRCHEM as unimportant
		<1.0[-11]	Ferguson et al., 1965	Not observed
		2.7[-11]	Neynaber et al., 1973	
43.	$N_2^+ + O_2 \rightarrow NO^+ + NO$	1 [-17 ± 2]	DNA 1948H, XIV-13	Estimated
44a.	$N_3^+ + O_2 \rightarrow NO^+ + N_2O$	(3.3 ± 1.0[-11]	DNA 1948H, XIV-17	Equal rates for three channels; N_3^+ not in AIRCHEM

	Reactions	Reference Values	References	Remarks
44b.	$N_3^+ + O_2 \rightarrow NO_2^+ + N_2$	(3.3 ± 1.0)[-11]	DNA 1948H, XIV-17	Equal rates for three channels; N_3^+ not in AIRCHEM
44c.	$N_3^+ + O_2 \rightarrow O_2^+ + N + N_2$	(3.3 ± 1.0)[-11]	DNA 1948H, XIV-17	Equal rates for three channels; N_3^+ not in AIRCHEM
45.	$N_4^+ + O_2 \rightarrow O_2^+ + 2N_2$	(4 ± 1)[-10]	DNA 1948H, XIV-18	N_4^+ not in AIRCHEM
		4 [-10]	Dunkin et al., 1971b	197°K
		1.0[-10]	Shahin, 1967	Corona discharge
46.	$O^+ + CO_2 \rightarrow O_2^+ + CO$	(1.1 ± 0.7)[-9]	DNA 1948H, XIV-4	Removed from AIRCHEM as unimportant
		1 [- 9]	Johnsen et al., 1970	0.039 eV
		5 [-10]	"	1.3 eV
		1.1[- 9]	Dunkin et al., 1968	300°K
		9 [-10]	"	600°K
47.	$O^+ + H \rightarrow H^+ + O$	6.8[-10]	DNA 1948H, XIII-1	H^+ not in AIRCHEM
48.	$O^+ + H_2 \rightarrow HO^+ + H$	2 [- 9]	DNA 1948H, XIV-3	HO^+ not in AIRCHEM
49.	$O^+ + H_2O \rightarrow H_2O^+ + O$	2.3[- 9]	DNA 1948H, XIII-7	H_2O^+ not in AIRCHEM
50a.	$O^+ + NO \rightarrow NO^+ + O$	<1.3[-12]	DNA 1948H, XIII-4	Removed from AIRCHEM as unimportant
50b.	$O^+ + NO \rightarrow O_2^+ + N$	<1 [-12]	DNA 1948H, XIV-2	Removed from AIRCHEM as unimportant
51.	$O^+ + NO + M \rightarrow NO^+ + O + M$	$1[-29 \pm 2](T/300)^{-1^{+1}_{-2}}$	DNA 1948H, XVIII-4	Estimated
52.	$O^+ + NO_2 \rightarrow NO_2^+ + O$	1.6[- 9]	DNA 1948H, XIII-5	393°K; NO_2^+ not in AIRCHEM
53a.	$O^+ + N_2O \rightarrow NO^+ + NO$	(2.3 ± 1.4)[-10]	Ryan, 1972	0.15-0.25 eV; removed from AIRCHEM as unimportant
53b.	$O^+ + N_2O \rightarrow N_2O^+ + O$	6.3[-10]	DNA 1948H, XIII-6	393°K; N_2O^+ not in AIRCHEM
		(2.2 ± 1.3)[-10]	Ryan, 1972	0.15-0.25 eV
54.	$O^+(^2D) + N_2 \rightarrow N_2^+ + O$	3 [-10 ± 1]	DNA 1948H, XIII-8	$O^+(^2D)$ not in AIRCHEM
55.	$O^+(^2D) + O_2 \rightarrow O_2^+(a,A) + O$	$3\ [-10^{+0.5}_{-1.0}]$	DNA 1948H, XIII-3	$O^+(^2D)$ and $O_2^+(a,A)$ not in AIRCHEM
56a.	$O_2^+ + Na \rightarrow Na^+ + O_2$	6.7[-10 ± 1]	DNA 1948H, XIII-16	Na^+ and Na not in AIRCHEM
56b.	$O_2^+ + Na \rightarrow NaO^+ + O$	7.7[-11]	DNA 1948H, XIV-11	NaO^+ and Na not in AIRCHEM

Reactions	Reaction Values	References	Remarks
57. $O_2^+ + NO_2 \rightarrow NO^+ + O_3$	1[-11 ± 2]	DNA 1948H, XIV-9	Estimated; removed from AIRCHEM as unimportant
58. $O_2^+ + O + M \rightarrow O_3^+ + M$	$1[-29 \pm 2](T/300)^{-1^{+1}_{-2}}$	DNA 1948H, XVIII-5	Estimated; O_3^+ not in AIRCHEM
59. $O_2^+(a^4\Pi_u) + N_2 \rightarrow N_2^+ + O_2$	5[-10]	DNA 1948H, XIII-17	$O_2^+(a^4\Pi_u)$ not in AIRCHEM
60. $O_2^+(N_2) + H_2O \rightarrow O_2^+(H_2O) + N_2$	(4 ± 2)[-9]	Howard et al., 1972	

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TABLE II

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TABLE III

Third-Body Effect on Positive-Ion-Neutral Association

Reaction Number	$\bar{k}_{He}$	$k_x/\bar{k}_{He}$				References*
		Ar	O_2	N_2	NO	
IIA11	3.4[-29]	2.65	2.65	4.12		Howard *et al.*, 1971
		2.29		4.71		Fehsenfeld *et al.*, 1971a
					4.71	Puckett & Teague, 1971
IIA16a	3.0[-28]	3.33	2.67	4.00		Howard *et al.*,1971
		2.67		3.33		Fehsenfeld *et al*,1971a
					3.67	Puckett & Teague,1971
IIA17a	3.65[-28]	3.29	2.47	3.84		Howard *et al*,1971
		4.11		5.48		Fehsenfeld *et al.*,1971a
					5.21	Puckett & Teague, 1971
IIA27	8.85[-29]		2.15			Howard *et al.*,1972
		2.26		3.16		Fehsenfeld *et al.*,1971b
Mean Values		2.94	2.49	4.09	4.53	

See references for Table II.

TABLE IV

Comparison of Reaction Frequencies for Reactions II.A.24 and II.A.25 in the Stratosphere and Mesosphere

$$O^+ + N_2 \rightarrow NO^+ + N \qquad \text{II.A.24}$$

$$O^+ + N_2 + M \rightarrow NO^+ + N + M \qquad \text{II.A.25}$$

Altitude (km)	T (°K)	M (cm^{-3})	N_2 (cm^{-3})	k_{24} (cm^3/s)	k_{25} (cm^6/s)	ν_{24} (s^{-1})	ν_{25} (s^{-1})
20*	216.7	1.849[18]	1.4[18]	1.41[-12]	3.07[-29]	2.0[6]	7.9[7]
40**	255.3	8.265[16]	6.5[16]	1.30[-12]	2.21[-29]	8.5[4]	1.2[5]
60**	249.3	6.669[15]	5.1[15]	1.32[-12]	2.32[-29]	6.7[3]	7.9[2]
80**	195.0	3.964[14]	3.0[14]	1.49[-12]	3.79[-29]	4.5[2]	4.5

**Temperature and number densities obtained from reference 4.*

***Temperature and number densities obtained from reference 2.*

TABLE V

Electron Reactions Other Than Ionization and Photodetachment

$$k = A(T/300)^{B}\exp(-C/T)$$

Two-body reactions in units of cm^3 $molecule^{-1}$ s^{-1} Three-body reactions in units of cm^6 $molecule^{-1}$ s^{-1}

A. Reactions in AIRCHEM

Reactions	Code Values A	B	C	Reference Values	References	Remarks
1. $H_3O^+ + e \rightarrow H + H_2O$	1.0[-6]*			$(1.3 \pm 0.3)[-6](T/300)^{(-0.2^{+0.1}_{-0.4})}$	DNA 1948H, IV-13	
				$(1.0 \pm 0.2)[-6]$	Leu et al., 1973	
				1.1[-6]	Lindinger, 1972	
2. $H_3O^+(OH) + e \rightarrow 2H_2O$	3.0[-6]			3 [-6](T/300)$^{-1}$	DNA 1948H, IV-19	Estimated
3. $H_3O^+(N_2) + e \rightarrow H + H_2O + N_2$	1.0[-6]					Estimated
4. $H^+(H_2O)_2 + e \rightarrow H + 2H_2O$	2.2[-6]			$(2.8 \pm 0.4)[-6](T/300)^{(-0.2^{+0.1}_{-0.4})}$	DNA 1948H, IV-14	
				$(2.0 \pm 0.3)[-6]$	Leu et al., 1973	540°K
				$(2.2 \pm 0.4)[-6]$	"	415°K
5. $H^+(H_2O)_3 + e \rightarrow H + 3H_2O$	4.0[-6]			$(5.1 \pm 0.7)[-6](T/300)^{(-0.2^{+0.1}_{-0.4})}$	DNA 1948H, IV-15	
				$(4.0 \pm 0.6)[-6]$	Leu et al., 1973	540°K
				$(4.2 \pm 0.6)[-6]$	"	415°K
				$(4.0 \pm 0.6)[-6]$	"	300°K
6. $H^+(H_2O)_4 + e \rightarrow H + 4H_2O$	4.9[-6]			$(6.1 \pm 1.2)[-6](T/300)^{(-0.2^{+0.1}_{-0.4})}$	DNA 1948H, IV-16	
				$(4.9 \pm 0.8)[-6]$	Leu et al., 1973	300°K
7. $H^+(H_2O)_5 + e \rightarrow H + 5H_2O$	6.0[-6]			$(7.4 \pm 1.5)[-6](T/300)^{(-0.2^{+0.1}_{-0.4})}$	DNA 1948H, IV-17	
				$(6.0 \pm 1.2)[-6]$	Leu et al., 1973	205°K

*Read 1.0[-6] as 1.0×10^{-6}.

	Reactions	Code Values A	B	C	Reference Values	References	Remarks
8a.	$NO^+ + e \rightarrow N + O$	1.0[-7]	-1.0		$(4.0 \pm 0.3)[-7](T/300)^{-1.0\pm0.2}$	DNA 1948, IV-3	Two channels
8b.	$\rightarrow N(^2D) + O$	3.0[-7]	-1.0		$(3.4 \pm 0.6)[-7]$	Mahdavi et al., 1971	300°K
					$(3.1 \pm 0.2)[-7]$	Weller & Biondi, 1968	450°K
					$(4.1^{+0.3}_{-0.2})[-7]$	"	300°K
					$(7.4 \pm 0.7)[-7]$	"	200°K
					$(4.5^{+3.5}_{-1.9})[-7]$	Mentzoni & Donohoe, 1967	300°K
					$(5 \pm 2)[-7]$	Young & St. John, 1966	300°K
					$(3.5^{+0.2}_{-0.5})[-7]$	Gunton & Shaw, 1965	358°K
					$(4.6^{+0.5}_{-1.3})[-7]$	"	298°K
					$(10^{+2}_{-4})[-7]$	"	196°K
9.	$NO^+(CO_2) + e \rightarrow CO_2 + NO$	1.0[-6]	-1.0				Estimated
10.	$NO^+(H_2O) + e \rightarrow H_2O + NO$	1.0[-6]	-1.0		$1[-6](T/300)^{-1}$	DNA 1948H, IV-8	Estimated
11.	$NO^+(H_2O)_2 + e \rightarrow 2H_2O + NO$	2.0[-6]	-1.0		$2[-6](T/300)^{-1}$	DNA 1948H, IV-9	Estimated
12.	$NO^+(H_2O)_3 + e \rightarrow 3H_2O + NO$	3.0[-6]	-1.0		$3[-6](T/300)^{-1}$	DNA 1948H, IV-10	Estimated
13.	$NO^+(N_2) + e \rightarrow NO + N_2$	1.0[-6]	-1.0				Estimated
14.	$NO_2^+ + e \rightarrow NO + O$	5.0[-7]	-1.0		$(5 \pm 4)[-7](T/300)^{-1^{+1}_{-1}}$	DNA 1948H, IV-6	
					$3[-7]$	Wyatt & Denson, 1968	225°K
15.	$N_2^+ + e \rightarrow N(^2D) + N$	2.7[-7]	-0.2		$(2.7 \pm 0.3)[-7](T/300)^{-0.2\pm0.2}$	DNA 1948H, IV-2	
					$(2.2 \pm 0.4)[-7]$	Mahdavi et al., 1971	300°K
					$(1.8^{+0.4}_{-0.2})[-7]$	Mehr & Biondi, 1969	300°K
					$(2.7 \pm 0.3)[-7]$	Kasner, 1967	200°-480°K

Reactions	Code Values A	B	C	Reference Values	References	Remarks
16. $O_2^+ + e \rightarrow O(^1D) + O$	2.1[-7]	-0.7		$(2.1 \pm 0.2)[-7](T/300)^{-0.7\pm0.3}$	DNA 1948H, IV-1	
				$(1.9 \pm 0.5)[-7]$	Mahdavi et al., 1971	300°K
				2.1[-7]	Zipf, 1970	
				$(1.95 \pm 0.2)[-7]$	Mehr & Biondi, 1969	300°K
				$(2.2 \pm 0.5)[-7]$	Kasner & Biondi, 1968	300°K
				2.1[-7]	Mentzoni, 1965	300°K
				1.4[-7]	"	894°K
17. $O_2^+(H_2O) + e \rightarrow H_2O + O_2$	1.5[-6]	-1.0		$1.5[-6](T/300)^{-1}$	DNA 1948H, IV-12	Estimated
18. $O_4^+ + e \rightarrow 2O_2$	2.0[-6]	-1.0		$(2.0 \pm 0.5)[-6](T/300)^{-1}$	DNA 1948H, IV-11	
				~2.3[-6]	Kasner & Biondi, 1968	205°K
19. $e + NO_2 \rightarrow NO_2^-$	4.0[-11]			4[-11]	DNA 1948H, IX-8	Saturated Three-Body
				4[-11]	Mahan & Walker, 1967	300°K, M = N_2
				1.4[-11]	Puckett et al., 1971	300°K, M = NO
20a. $e + O_2 + N_2 \rightarrow O_2^- + N_2$	1.0[-31]			$(1.0 \pm 0.5)[-31]$	DNA 1948H, IX-4	
				1.6[-31]	Hirsh et al., 1969	300°K
				$(1.0 \pm 0.5)[-31]$	Pack & Phelps, 1966a	300°K
				$(1.0 \pm 0.1)[-31]$	Van Lint et al., 1965	300°K
20b. $O_2^- + N_2 \rightarrow e + O_2 + N_2$	1.9[-12]	1.5	4990	$(1.9\pm0.4)[-12](T/300)^{1.5}\exp(-4990/T)$	DNA 1948H, X-3a	375°-600°K
				$(1.9\pm0.4)[-12](T/300)^{1.5}\exp(-4990/T)$	Pack & Phelps, 1966a	375°-600°K
21a. $e + O_2 + O_2 \rightarrow O_2^- + O_2$	1.4[-29]	-1.0	600	$(1.4\pm0.2)[-29](T/300)^{-1}\exp(-600/T)$	DNA 1948H, IX-3	195°-600°K
				$(5.6 \pm 1.3)[-30](T/300)^{-0.5}$	Spence & Schulz, 1972	300°-750°K; 0.09 eV
				$(2.1 \pm 0.2)[-30]$	Truby, 1972	300°K
				$(1.5 \pm 0.2)[-30]$	"	200°K
				$(7.2 \pm 1.4)[-31]$	"	113°K
				$(2.12 \pm 0.14)[-30]$	Hirsh et al., 1969	300°K
				$(2.0 \pm 0.2)[-30]$	Pack & Phelps, 1966a	300°K
				$(2.8 \pm 0.5)[-30]$	"	530°K

	Reactions			Code Values A	B	C	Reference Values	References	Remarks
21b.	$O_2^- + O_2$	→	$e + O_2 + O_2$	2.7[-10]	0.5	5590	$(2.7\pm0.3)[-10](T/300)^{0.5}\exp(-5590/T)$	DNA 1948H, X-3b	375°-600°K
							9 [-17]	Pack & Phelps, 1966a	375°K
							1.4[-14]	"	575°K
							4 [-20]	Phelps & Pack, 1961	230°K
22.	$e + O_3$	→	$O^- + O_2$	9.0[-12]	1.5		9 $[-12](T/300)^{1.5}$	DNA 1948H, XI-2a	200°-300°K
							9 $[-12](T/300)^{1.5}$	Stelman et al., 1972	200°-300°K
23.	$O^- + CO$	→	$e + CO_2$	4.4[-10]			(4.4 ± 2.0)[-10]	DNA 1948H, XII-9	
							(7.3 ± 0.7)[-10]	Parkes, 1972a	
							(4.4 ± 1.3)[-10]	Ferguson et al., 1969	
							(6.5 ± 1.0)[-10]	Moruzzi et al., 1968	
24.	$O^- + H_2$	→	$e + H_2O$	7.5[-10]			(7.5 ± 3.0)[-10]	DNA 1948H, XII-8	
							(7.0 ± 0.5)[-10]	Parkes, 1972b	
							(7.2 ± 1.0)[-10]	Moruzzi et al., 1968	
							6 [-10]	Ferguson et al., 1969	
25.	$O^- + N$	→	$e + NO$	2.2[-10]			(2.2 ± 0.5)[-10]	DNA 1948H, XII-4	
							2.2[-10]	Fehsenfeld et al., 1967	
26.	$O^- + NO$	→	$e + NO_2$	2.0[-10]			(2.0 ± 0.8)[-10]	DNA 1948H, XII-6	
							1.6[-10]	Ferguson et al., 1969	
							2.2[-10]	Moruzzi et al., 1968	
27.	$O^- + O$	→	$e + O_2$	2.0[-10]			(2.0 ± 0.1)[-10]	DNA 1948H, XII-1	
							2 [-10]	Fehsenfeld et al., 1969b	
28.	$O^- + O_2(^1\Delta_g)$	→	$e + O_3$	3.0[-10]			(3 ± 2)[-10]	DNA 1948H, XII-3	
							~3 [-10]	Fehsenfeld et al., 1969a	
29.	$O_2^- + N$	→	$e + NO_2$	3.0[-10]			(5 ± 1.5)[-10]	DNA 1948H, XII-11	
							4 [-10]	Fehsenfeld et al., 1967	Two channels
30.	$O_2^- + O$	→	$e + O_3$	3.0[-10]			(3 ± 1.5)[-10]	DNA 1948H, XII-10	
							3 [-10]	Fehsenfeld et al., 1969b	
31.	$O_2^- + O_2(^1\Delta_g)$	→	$e + 2O_2$	2.0[-10]			2 [-10]	DNA 1948	
							~2 [-10]	Fehsenfeld et al., 1969a	

B. Reactions Omitted from AIRCHEM

Reactions	Reference Values	References	Remarks
1. $H^+(H_2O)_6 + e \rightarrow H + 6H_2O$	$(9.3 \pm 2.0)[-6](T/300)^{-0.2^{+0.1}_{-0.4}}$	DNA 1948H, IV-18	$H^+(H_2O)_6$ not included in AIRCHEM
	(7.5 ± 1.5)[-6]	Leu et al., 1973	205°K
2. $N^+ + e \rightarrow N + h\nu$	$(3.5 \pm 1.0)[-12](T/300)^{-0.7\pm0.1}$	DNA 1948H, I-2	N^+ reacts faster with O_2
3. $N^+ + e + e \rightarrow e + N$	$1\ [-19](T/300)^{-4.5}$	DNA 1948H, III-2	N^+ reacts faster with O_2
4. $NO^+ + e + e \rightarrow e + NO$	$1\ [-19](T/300)^{-4.5}$	DNA 1948H, III-2	Dissociative recombination more likely
5. $NO^+(NO) + e \rightarrow 2NO$	$(1.7 \pm 0.5)[-6](T/300)^{-1}$	DNA 1948H, IV-7	$NO^+(NO)$ not included in AIRCHEM
	(1.7 ± 0.4)[-6]	Weller & Biondi, 1968	300°K
	1.5[-6]	Wyatt & Denson, 1968	295°K
6. $NO_2^+ + e + e \rightarrow e + NO_2$	$1\ [-19](T/300)^{-4.5}$	DNA 1948H, III-2	Dissociative recombination more likely
7. $N_2^+ + e + e \rightarrow e + N_2$	$1\ [-19](T/300)^{-4.5}$	DNA 1948H, III-2	Only important at very early times in highly ionized regions
8. $N_4^+ + e \rightarrow 2N_2$	$(2 \pm 1)[-6](T/300)^{-1}$	DNA 1948H, IV-5	N_4^+ not included in AIRCHEM
	4 [-6]	Wyatt & Denson, 1968	130°K
	2 [-6]	"	290°K
	7 [-6]	"	670°K
	~2 [-6]	Kasner & Biondi, 1965	300°K
9. $O^+ + e \rightarrow O + h\nu$	$(3.5 \pm 1.0)[-12](T/300)^{-0.7\pm0.1}$	DNA 1948H, I-1	O^+ reacts faster with N_2 and O_2
10. $O^+ + e + e \rightarrow e + O$	$1\ [-19](T/300)^{-4.5}$	DNA 1948H, III-2	O^+ reacts faster with N_2 and O_2
11. $O_2^+ + e + e \rightarrow e + O_2$	$1\ [-19](T/300)^{-4.5}$	DNA 1948H, III-2	Only important at very early times in highly ionized regions
12. $X^+ + e + M \rightarrow$ Products	$1\ [-26 \pm 1](T/300)^{-2.5}$	DNA 1948H, III-1	X represents any species; can be important in highly ionized troposphere
13. $e + NO + M \rightarrow$ Products	8 [-31]	DNA 1948H, IX-7	M = NO; attachment to O_2 faster
	6.8[-32]	Puckett & Teague, 1971	M = NO
	(1.3 ± 0.2)[-31]	Weller & Biondi, 1968	M = NO

	Reactions			Reference Values	References	Remarks
14.	$e + NO_2$	→	$NO_2^- + h\nu$	1 [-17 ± 2]	DNA 1948H, VII-4	VA19 faster
15.	$e + O$	→	$O^- + h\nu$	(1.3 ± 0.1)[-15]	DNA 1948H, VII-1	VA20a and VA22 faster
16.	$e + O + M$	→	$O^- + M$	$6.5[-29](T/300)^{-2\pm0.5}\exp(-9000/T)$	DNA 1948H, IX-1	VA20a and VA22 faster
17.	$e + O_2$	→	$O_2^- + h\nu$	2 [-19 ± 1]	DNA 1948H, VII-2	VA20a faster
18.	$e + O_2 + M$	→	$O_2^- + M$	(3.3 ± 0.7)[-30]	DNA 1948H, IX-6	$M = CO_2$
				(3.3 ± 0.7)[-30]	Pack & Phelps, 1966b	$M = CO_2$
				(1.4 ± 0.2)[-29]	DNA 1948H, IX-5	$M = H_2O$
				(1.4 ± 0.2)[-29]	Pack & Phelps, 1966b	$M = H_2O$
19.	$e + O_3$	→	$O_3^- + h\nu$	1 [-17 ± 2]	DNA 1948H, VII-3	VA22 faster
20.	$HO^- + H$	→	$e + H_2O$	(1.0 ± 0.5)[- 9]	Ferguson et al., 1969	300°K; HO^- not included in AIRCHEM
21.	$HO^- + NO_2$	→	$e + HNO_3$	(1.0 ± 0.3)[- 9]	Ferguson et al., 1969	300°K, HO^- not included in AIRCHEM
22.	$HO^- + O$	→	$e + HO_2$	(2.0 ± 0.6)[-10]	DNA 1948H, XII-13	HO^- not included in AIRCHEM
				(2.0 ± 1.0)[-10]	Ferguson et al., 1969	300°K
23.	$O^- + H$	→	$e + HO$	1 [-10]		Estimated; removed from AIRCHEM
24.	$O_2^- + H_2$	→	$e + H_2O_2$	1 [-12]		Estimated; removed from AIRCHEM

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FOR
TABLE V

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TABLE VI

Two- and Three-Body Negative-Ion Reactions Other Than Electron Attachment, Electron Detachment, Photodissociation, and Ion-Ion Recombination

$$k = A(T/300)^{B} \exp(-C/T)$$

Two-body reactions in units of cm^3 $molecule^{-1}$ s^{-1} Three-body reactions in units of cm^6 $molecule^{-1}$ s^{-1}

A. Reactions in AIRCHEM

Reactions	Code Values A	B	C	Reference Values	References	Remarks
1. $CO_3^- + H_2O + M \rightarrow CO_3^-(H_2O) + M$	1.0[-28]*	-1.0		~1 [-28]	Fehsenfeld & Ferguson, 1973	300°K
2. $CO_3^- + NO \rightarrow NO_2^- + CO_2$	1.8[-11]			(9 ± 3)[-12]	DNA 1948H, XVI-19	
				1.8[-11]	Fehsenfeld & Ferguson, 1973	300°K
3. $CO_3^- + NO_2 \rightarrow NO_3^- + CO_2$	8.0[-11]			8.0[-11]	DNA 1948H, XVI-20	
				8.0[-11]	Ferguson, 1969	300°K
4. $CO_3^- + O \rightarrow O_2^- + CO_2$	8.0[-11]			(8.0 ± 2.4)[-11]	DNA 1948H, XVI-18	
				8.0[-11]	Fehsenfeld et al., 1967	300°K
5. $CO_3^-(H_2O) + NO \rightarrow NO_2^-(H_2O) + CO_2$	1.8[-11]			~1.8[-11]	Fehsenfeld & Ferguson, 1973	300°K
6. $CO_4^- + H_2O + M \rightarrow CO_4^-(H_2O) + M$	5.0[-29]	-1.0			Estimated	
7. $CO_4^- + NO \rightarrow NO_3^{-*} + CO_2$	4.8[-11]			4.8[-11]	DNA 1948H, XVI-22	
				4.8[-11]	Fehsenfeld et al., 1969	300°K
8. $CO_4^- + O \rightarrow CO_3^- + O_2$	1.5[-10]			1.5[-10]	DNA 1948H, XVI-21	
				1.5[-10]	Fehsenfeld et al., 1969	300°K
9. $CO_4^- + O_3 \rightarrow O_3^- + CO_2 + O_2$	1.3[-10]			1.3[-10]	Fehsenfeld, 1973	
10. $CO_4^-(H_2O) + NO \rightarrow NO_3^-(H_2O) + CO_2$	5.0[-10]				Estimated	
11. $NO_2^- + H_2O + M \rightarrow NO_2^-(H_2O) + M$	1.3[-28]	-1.0		1.3[-28](T/300)$^{-1^{+1}_{-2}}$	DNA 1948H, XXI-7	
				(1.3 ± 0.3)[-28]	Puckett & Lineberger, 1970	M = NO; 293°K
				8.4[-29]	Payzant et al., 1972	M = O_2; 300°K
				6 [-29]	"	M = Ar; 300°K

*Read 1.0[-28] as 1.0×10^{-28}.

	Reactions	Code Values A	B	C	Reference Values	References	Remarks
12.	$NO_2^- + NO_2 \rightarrow NO_3^- + NO$	4.0[-12]			4 [-12]	DNA 1948H, XVI-10	
					~4 [-12]	Fehsenfeld et al., 1969	300°K
13.	$NO_2^- + O_3 \rightarrow NO_3^- + O_2$	1.8[-11]			1.8[-11]	DNA 1948H, XVI-9	
					1.8[-11]	Fehsenfeld & Ferguson, 1968	300°K
14.	$NO_2^-(H_2O) + O_3 \rightarrow NO_3^-(H_2O) + O_2$	5.0[-10]				Estimated	
15.	$NO_3^- + H_2O + M \rightarrow NO_3^-(H_2O) + M$	7.5[-29]	-1.0		7.5[-29]	Payzant et al., 1972	$M = O_2$; 300°K
16.	$O^- + CO_2 + M \rightarrow CO_3^- + M$	3.1[-28]	-1.0		$8.0[-29](T/300)^{-1^{+1}_{-2}}$	DNA 1948H, XXI-3	
					(1.1 ± 0.1)[-27]	Parkes, 1972a	$M = CO_2$; 300°K
					(3.1 ± 0.3)[-28]	"	$M = O_2$; 300°K
					2.6[-28]	Adams et al., 1970	M = He; 200°K
					9 [-29]	Moruzzi & Phelps, 1966	$M = CO_2$; E/P = 50 V $cm^{-1}torr^{-1}$
					1.5[-28]	Bohme et al., 1969	M = He; 280°K
17.	$O^- + NO_2 \rightarrow NO_2^- + O$	1.2[- 9]			1.2[- 9]	DNA 1948H, XV-3	
					1.2[- 9]	Ferguson et al., 1969	300°K
					1.1[- 9]	Rutherford & Turner, 1967	Extrapolated to 300°K
					1.0[- 9]	Paulson, 1966	
18.	$O^- + O_2 + M \rightarrow O_3^- + M$	1.1[-30]	-1.0		$(1.1 \pm 0.1)[-30](T/300)^{-1^{+1}_{-2}}$	DNA 1948H, XXI-1	
					1.4[-30]	Payzant & Kebarle, 1972	$M = O_2$; 300°K
					(1.05 ± 0.1)[-30]	Parkes, 1971	$M = O_2$; 298°K
					1.2[-30]	Pack & Phelps, 1971	$M = O_2$; 300°K
					(1.0 ± 0.2)[-30]	Snuggs et al., 1971	$M = O_2$; low E/N
19.	$O^- + O_3 \rightarrow O_3^- + O$	5.3[-10]			(5.3 ± 2.0)[-10]	DNA 1948H, XV-2	
					5.3[-10]	Ferguson et al., 1969	300°K
20.	$O_2^- + CO_2 + M \rightarrow CO_4^- + M$	2.0[-29]	-1.0		$2.0[-29](T/300)^{-1^{+1}_{-2}}$	DNA 1948H, XXI-6	
					4.7[-29]	Adams et al., 1970	M = He; 200°K
					9.0[-30]	Moruzzi & Phelps, 1966	$M = CO_2$; 300°K
					2.0[-29]	"	$M = O_2$; 300°K

	Reactions	Code Values A	B	C	Reference Values	References	Remarks
21.	$O_2^- + H_2O + M \rightarrow O_2^-(H_2O) + M$	3.0[-28]	-1.0		$3\ [-28](T/300)^{-1^{+1}_{-2}}$	DNA 1948H, XXI-10	
					2.2[-28]	Fehsenfeld & Ferguson, 1973	M = O_2; 300°K
					1.6[-28]	Payzant & Kebarle, 1972	M = O_2; 300°K
					3 [-28]	Pack & Phelps, 1971	M = O_2; 300°K
22.	$O_2^- + N \rightarrow O^- + NO$	1.0[-10]				Fehsenfeld et al., 1967	V-A-29 more likely
23.	$O_2^- + NO_2 \rightarrow NO_2^- + O_2$	8.0[-10]			8 [-10]	DNA 1948H, XV-6	
					8.0[-10]	Ferguson et al., 1969	300°K
					1.5[- 9]	Rutherford & Turner, 1967	Extrapolated to 300°K
24.	$O_2^- + O \rightarrow O^- + O_2$	3.3[-10]			<1 [-10]	DNA 1948H, XV-4	Estimated
					3.28[-10]	Neynaber et al., 1973	Extrapolated to 300°K
25a.	$O_2^- + O_2 + N \rightarrow O_4^- + N$	3.5[-31]	-1.0		$(3.5 \pm 0.5)[-31](T/300)^{-1^{+1}_{-2}}$	DNA 1948H, XXI-4	
					5.1[-31]	Payzant & Kebarle, 1972	M = O_2; 300°K
					3.5[-31]	Truby, 1972	M = O_2; 300°K
					~9 [-31]	"	M = O_2; 213°K
					(3.0 ± 0.5)[-31]	Parkes, 1971	M = O_2; 298°K
					4 [-31]	Pack & Phelps, 1971	M = O_2; 300°K
					3 [-31]	McKnight & Sawina, 1971	M = O_2; 305°K
					3.4[-31]	Adams et al., 1970	M = He; 200°K
25b.	$O_4^- + N \rightarrow O_2^- + O_2 + N$	1.0[- 3]	-1.0	7500	$1[-3](T/300)^{-1}\exp(-7500/T)$	DNA 1948H, XXII-1	
					1.6[-14]	Payzant & Kebarle, 1972	M = O_2; 300°K
					(7 ± 1)[-15]	Parkes, 1971	M = O_2; 298°K
					2.7[-14]	Pack & Phelps, 1971	M = O_2; 300°K
					2 [-14]	McKnight & Sawina, 1971	M = O_2; 310°K
26.	$O_2^- + O_3 \rightarrow O_3^- + O_2$	4.0[-10]			(4.0 ± 1.3)[-10]	DNA 1948H, XV-5	
					4.0[-10]	Ferguson et al., 1969	300°K
27.	$O_2^-(H_2O) + CO_2 \rightarrow CO_4^- + H_2O$	5.8[-10]			5.8[-10]	DNA 1948H, XVI-24	
					5.8[-10]	Adams et al., 1970	300°K

	Reactions	Code Values A	B	C	Reference Values	References	Remarks
28.	$O_2^-(H_2O) + NO \rightarrow NO_3^{-*} + H_2O$	3.1[-10]			3.1[-10]	DNA 1948H, XVI-23	
					3.1[-10]	Adams et al., 1970	300°K
29.	$O_2^-(H_2O) + O_3 \rightarrow O_3^- + H_2O + O_2$	3.1[-10]			3.1[-10]	Fehsenfeld & Ferguson, 1973	300°K; two channels
30.	$O_3^- + CO_2 \rightarrow CO_3^- + O_2$	5.5[-10]			(4.0 ± 1.2)[-10]	DNA 1948H, XVI-6	
					(5.5 ± 0.5)[-10]	Parkes, 1972a	300°K
					4.0[-10]	Fehsenfeld et al., 1967	300°K
31.	$O_3^- + NO \rightarrow NO_2^- + O_2$	1.0[-11]			(1.0 ± 0.3)[-11]	DNA 1948H, XVI-4	
					1.0[-11]	Fehsenfeld et al., 1967	300°K
32a.	$O_3^- + NO_2 \rightarrow NO_2^- + O_3$	1.4[-10]			1.9[-11]	DNA 1948H, XV-8	Products uncertain
					2.8[-10]	Dunkin et al., 1972	300°K; two channels
					7 [-10]	Rutherford & Turner, 1967	Extrapolated to 300°K
32b.	$O_3^- + NO_2 \rightarrow NO_3^- + O_2$	1.4[-10]			2 [-11]	DNA 1948H, XVI-5	
					2.8[-10]	Dunkin et al., 1972	300°K; two channels
33a.	$O_4^- + CO_2 \rightarrow CO_4^- + O_2$	4.3[-10]			4.3[-10]	DNA 1948H, XVI-17	
					4.3[-10]	Fehsenfeld et al., 1969	300°K
33b.	$CO_4^- + O_2 \rightarrow O_4^- + CO_2$	4.3[-10]		3000	4.3[-10]exp(-3000/T)	DNA 1948H, XVI-26	
34.	$O_4^- + H_2O \rightarrow O_2^-(H_2O) + O_2$	1.4[- 9]			1.4[- 9]	DNA 1948H, XVI-16	
					1.4[- 9]	Pack & Phelps, 1971	300°K
					1.5[- 9]	Payzant & Kebarle, 1972	300°K
					~1 [- 9]	Parkes, 1971	300°K
35.	$O_4^- + NO \rightarrow NO_3^{-*} + O_2$	2.5[-10]			2.5[-10]	DNA 1948H, XVI-15	
					2.5[-10]	Fehsenfeld et al., 1969	300°K
36.	$O_4^- + O \rightarrow O_3^- + O_2$	4.0[-10]			4 [-10]	DNA 1948H, XVI-14	
					4 [-10]	Fehsenfeld et al., 1969	300°K
37.	$O_4^- + O_3 \rightarrow O_3^- + 2O_2$	5.0[-10]					Estimated
38.	$NO_3^{-*} + NO \rightarrow NO_2^- + NO_2$	1.5[-11]			1.5[-11]	DNA 1948H, XVI-25	
					1.5[-11]	Adams et al., 1970	300°K

B. Reactions Omitted from AIRCHEM

	Reactions	Reference Values	References	Remarks
1a.	$CO_3^-(H_2O) + H_2O + M \rightarrow CO_3^-(H_2O)_2 + M$	$K_{eq} = 6.2[-17]$ cm^3	Fehsenfeld & Ferguson, 1973	M = CO_2; 300°K; $CO_3^-(H_2O)_2$ not in AIRCHEM
1b.	$CO_3^-(H_2O)_2 + M \rightarrow CO_3^-(H_2O) + H_2O + M$			
2.	$CO_3^-(H_2O) + NO_2 \rightarrow$ Products	~1.5[-10]	Fehsenfeld & Ferguson, 1973	300°K
3a.	$CO_4^-(H_2O) + H_2O \rightarrow O_2^-(H_2O)_2 + CO_2$	$K_{eq} = 15$	Fehsenfeld & Ferguson, 1973	300°K; $O_2^-(H_2O)_2$ not in AIRCHEM
3b.	$O_2^-(H_2O)_2 + CO_2 \rightarrow CO_4^-(H_2O) + H_2O$			
4.	$H^- + NO_2 \rightarrow NO_2^- + H$	2.9[- 9]	DNA 1948H, XV-12	H^- not in AIRCHEM
		(2.9 ± 0.9)[-9]	Ferguson et al., 1969	
5.	$HO^- + NO_2 \rightarrow NO_2^- + HO$	1 [- 9]	DNA 1948H, XV-13	HO^- not in AIRCHEM
		(1.0 ± 0.3)[-9]	Ferguson et al., 1969	
6.	$NO^- + O_2 \rightarrow O_2^- + NO$	5 [-10]	DNA 1948H, XV-10	NO^- not in AIRCHEM
		5.0[-10]	McFarland et al., 1972	
		3.5[-10]	Tiernan & Hughes, 1969	
7.	$NO_2^- + NO_3 \rightarrow NO_3^- + NO_2$	5 [-10]	DNA 1948H, XV-11	Estimated; NO_3 not in AIRCHEM
8.	$NO_2^-(H_2O) + M \rightarrow NO_2^- + H_2O + M$	1.6[-15]	Payzant et al., 1972	M = O_2; 300°K; reverse of VI-A-11
		1.1[-15]	"	M = Ar; 300°K
		5.6[-16]	"	M = He; 300°K
9a.	$NO_2^-(H_2O) + H_2O + M \rightarrow NO_2^-(H_2O)_2 + M$	3.8[-29]	Payzant et al., 1972	M = O_2; 300°K; $NO_2^-(H_2O)_2$ not in AIRCHEM
9b.	$NO_2^-(H_2O)_2 + M \rightarrow NO_2^-(H_2O) + H_2O + M$	5.8[-14]	Payzant et al., 1972	M = O_2; 300°K
10a.	$NO_2^-(H_2O)_2 + H_2O + M \rightarrow NO_2^-(H_2O)_3 + M$	$K_{eq} = 3.9[-17]$ cm^3	Fehsenfeld & Ferguson, 1973	300°K; $NO_2^-(H_2O)_2$ not in AIRCHEM
10b.	$NO_2^-(H_2O)_3 + M \rightarrow NO_2^-(H_2O)_2 + H_2O + M$			
11.	$NO_3^- + NO \rightarrow NO_2^- + NO_2$	<1 [-12]	DNA 1948H, XVI-13	300°K; reverse of VI-A-12
12a.	$NO_3^-(H_2O) + H_2O + M \rightarrow NO_3^-(H_2O)_2 + M$	$K_{eq} = 2.0[-16]$ cm^3	Fehsenfeld & Ferguson, 1973	M = O_2; 300°K; $NO_3^-(H_2O)_2$ not in AIRCHEM
12b.	$NO_3^-(H_2O)_2 + M \rightarrow NO_3^-(H_2O) + H_2O + M$			
13.	$NO_3^-(H_2O) + M \rightarrow NO_3^- + H_2O + M$	1.4[-14]	Payzant et al., 1972	M = O_2; 300°K; reverse of VI-A-15

	Reactions			Reaction Values	References	Remarks
14.	$O^- + H_2$	→	$HO^- + H$	$(3.3 \pm 0.5)[-11]$	Parkes, 1972b	HO^- not in AIRCHEM
15.	$O^- + H_2O + M$	→	$O^-(H_2O) + M$	$1.0[-28](T/300)^{-1^{+1}_{-2}}$	DNA 1948H, XXI-9	$O^-(H_2O)$ not in AIRCHEM
				$1.0[-28]$	Pack & Phelps, 1971	$M = O_2$; 300°K
16.	$O^- + NO + M$	→	$NO_2^- + M$	$1[-29 \pm 2](T/300)^{-1^{+1}_{-2}}$	DNA 1948H, XXI-2	Estimated; VII-A-18 more likely
17.	$O^- + NO_3$	→	$NO_3^- + O$	$5.0[-10]$		Estimated; NO_3 not now in AIRCHEM
18.	$O^- + N_2 + M$	→	$N_2O^- + M$	$3[-31](T/300)^{-1^{+1}_{-2}}$	DNA 1948H, XXI-8	N_2O^- not in AIRCHEM
				~ 4 [-32]	Adams et al., 1970	M = He; 200°K
				1.3[-30]	Ferguson, 1969	M = He; 80°K
19.	$O^- + N_2O$	→	$NO^- + NO$	$(2.0 \pm 0.6)[-11]$	DNA 1948H, XVI-1	NO^- not in AIRCHEM
				$(1.95 \pm 0.06)[-10]$	Parkes, 1972c	
				$(2.5 \pm 0.5)[-10]$	Marx et al., 1973	Ion cyclotron resonance measurement
				$(2.2 \pm 0.4)[-10]$	Marx et al., 1973	Flowing afterglow measurement; 273°-500°K
				1.4[-10]	Tiernan & Hughes, 1969	
20.	$O_2^- + N + M$	→	$NO_2^- + M$	$1.0[-29](T/300)^{-1}$		Estimated; VI-A-25 more likely
21.	$O_2^- + NO$	→	$NO_2^- + O$	$1.0[-12]$		Estimated
				Not observed	Ferguson, 1967	
22.	$O_2^- + NO + M$	→	$NO_3^- + O$	$1.0[-30](T/300)^{-1}$		Estimated; VI-A-25 more likely
23.	$O_2^- + NO_3$	→	$NO_3^- + O_2$	5 [-10]	DNA 1948H, XV-7	Estimated; NO_3 not now in AIRCHEM
24.	$O_2^- + N_2 + M$	→	$O_2^-(N_2) + M$	3 [-32]$(T/300)^{-1^{+1}_{-2}}$	DNA 1948H, XXI-5	$O_2^-(N_2)$ not in AIRCHEM
				~ 4 [-32]	Adams et al., 1970	M = He; 200°K
25a.	$O_2^-(H_2O) + H_2O + M$	→	$O_2^-(H_2O)_2 + M$	4 [-28]$(T/300)^{-1^{+1}_{-2}}$	DNA 1948H, XXI-12	$O_2^-(H_2O)_2$ not in AIRCHEM
				4 [-28]	Pack & Phelps, 1971	$M = O_2$; 300°K
				5.4[-28]	Payzant & Kebarle, 1972	$M = O_2$; 300°K
25b.	$O_2^-(H_2O)_2 + M$	→	$O_2^-(H_2O) + H_2O + M$	7.1[-15]	Pack & Phelps, 1971	$M = O_2$; 300°K
				1.1[-14]	Payzant & Kebarle, 1972	$M = O_2$; 300°K
26.	$O_2^-(H_2O) + O$	→	$O_3^- + H_2O$	$1.0[-10]$		Estimated

	Reactions			Reaction Values	References	Remarks
27.	$O_2^-(H_2O) + O_2$	→	$O_4^- + H_2O$	$(2.5 \pm 1.0)[-15]$	Parkes, 1971	298°K; reverse of VI-A-34
28.	$O_2^-(H_2O) + O_3$	→	$O_3^-(H_2O) + O_2$	3.1[-10]	Fehsenfeld & Ferguson, 1973	Sum for two channels; see VI-A-29; $O_3^-(H_2O)$ not in AIRCHEM
29a.	$O_2^-(H_2O)_2 + O_3$	→	$O_3^-(H_2O) + H_2O + O_2$	3.4[-10]	Fehsenfeld & Ferguson, 1973	Sum for two channels
29b.		→	$O_3^-(H_2O)_2 + O_2$			
30.	$O_3^- + H_2O + M$	→	$O_3^-(H_2O) + M$	$2.1[-28](T/300)^{-1^{+1}_{-2}}$	DNA 1948H, XXI-11	$O_3^-(H_2O)$ not in AIRCHEM
				2.1[-28]	Pack & Phelps, 1971	M = O_2; 300°K
				2.7[-28]	Fehsenfeld & Ferguson, 1973	M = O_2; 300°K
31.	$O_3^- + NO_3$	→	$NO_3^- + O_3$	5 [-10]	DNA 1948H, XV-9	Estimated; NO_3 not now in AIRCHEM
32.	$O_3^- + O$	→	$O_2^- + O_2$	$1\ [-11^{+1}_{-2}]$	DNA 1948H, XVI-2	
33a.	$O_3^-(H_2O) + CO_2$	→	$CO_3^- + H_2O + O_2$	~3 [-10]	Fehsenfeld & Ferguson, 1973	Sum for two channels; $O_3^-(H_2O)$ not in AIRCHEM
33b.		→	$CO_3^-(H_2O) + O_2$			
34a.	$O_3^-(H_2O) + H_2O + M$	→	$O_3^-(H_2O)_2 + M$	$K_{eq} = 1.5[-15]$ cm^3	Fehsenfeld & Ferguson, 1973	M = O_2; 300°K; $O_3^-(H_2O)$ not in AIRCHEM
34b.	$O_3^-(H_2O)_2 + M$	→	$O_3^-(H_2O) + H_2O + M$			
35a.	$O_3^-(H_2O)_2 + CO_2$	→	$CO_3^-(H_2O) + H_2O + O_2$	~2 [-10]	Fehsenfeld & Ferguson, 1973	Sum for two channels; $O_3^-(H_2O)_2$ not in AIRCHEM
35b.		→	$CO_3^-(H_2O)_2 + O_2$			
36a.	$O_3^-(H_2O)_2 + H_2O + M$	→	$O_3^-(H_2O)_3 + M$	$K_{eq} = 8.2[-17]$ cm^3	Fehsenfeld & Ferguson, 1973	M = O_2; 300°K; $O_3^-(H_2O)_2$ not in AIRCHEM
36b.	$O_3^-(H_2O)_3 + M$	→	$O_3^-(H_2O)_2 + H_2O + M$			

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TABLE VI

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TABLE VII

Ion-Ion Recombination

$k = A(T/300)^B \exp(-C/T)$

Two-body reactions in units of cm^3 molecule^{-1} s^{-1} Three-body reactions in units of cm^6 molecule^{-1} s^{-1}

A. Reactions in AIRCHEM

	Reactions			Code Values A	B	C	Reference Values	References	Remarks
1.	$H_3O^+ + CO_3^-$	→	$CO_2 + HO + H_2O$	2.0[-7]*	-0.5				Estimated based on Smith et al., 1973
2.	$H_3O^+ + CO_3^-(H_2O)$	→	$CO_2 + H + 2H_2O + O$	"	"				"
3.	$H_3O^+ + CO_4^-$	→	$CO_2 + HO_2 + H_2O$	"	"				"
4.	$H_3O^+ + CO_4^-(H_2O)$	→	$CO_2 + H + 2H_2O + O_2$	"	"				"
5.	$H_3O^+ + NO_2^-$	→	$HO + H_2O + NO$	"	"				"
6.	$H_3O^+ + NO_2^-(H_2O)$	→	$H + 2H_2O + NO_2$	"	"				"
7.	$H_3O^+ + NO_3^-$	→	$HO + H_2O + NO_2$	"	"				"
8.	$H_3O^+ + NO_3^-(H_2O)$	→	$H + 2H_2O + NO_2 + O$	"	"				"
9.	$H_3O^+ + O^-$	→	$HO + H_2O$	"	"				"
10.	$H_3O^+ + O_2^-$	→	$H + H_2O + O_2$	"	"				"
11.	$H_3O^+ + O_2^-(H_2O)$	→	$H + 2H_2O + O_2$	"	"				"
12.	$H_3O^+ + O_3^-$	→	$HO + H_2O + O_2$	"	"				"
13.	$H_3O^+ + O_4^-$	→	$HO_2 + H_2O + O_2$	"	"				"
14.	$H_3O^+ + OONO^-$	→	$HO_2 + H_2O + NO$	"	"				"
15.	$H^+(H_2O)_2 + CO_3^-$	→	$CO_2 + HO + 2H_2O$	"	"				"
16.	$H^+(H_2O)_2 + CO_3^-(H_2O)$	→	$CO_2 + H + 3H_2O + O$	"	"				"
17.	$H^+(H_2O)_2 + CO_4^-$	→	$CO_2 + HO_2 + 2H_2O$	"	"				"

*Read 2.0[-7] as 2.0×10^{-7}.

	Reactions	Code Values A	B	C	Reference Values	References	Remarks
18.	$H^+(H_2O)_2 + CO_4^-(H_2O) \rightarrow CO_2 + H + 3H_2O + O_2$	2.0[-7]	-0.5				Estimated based on Smith et al., 1973
19.	$H^+(H_2O)_2 + NO_2^- \rightarrow HO + 2H_2O + NO$	"	"				"
20.	$H^+(H_2O)_2 + NO_2^-(H_2O) \rightarrow H + 3H_2O + NO_2$	"	"				"
21.	$H^+(H_2O)_2 + NO_3^- \rightarrow HO + 2H_2O + NO_2$	"	"				"
22.	$H^+(H_2O)_2 + NO_3^-(H_2O) \rightarrow H + 3H_2O + NO_2 + O$	"	"				"
23.	$H^+(H_2O)_2 + O^- \rightarrow HO + 2H_2O$	"	"				"
24.	$H^+(H_2O)_2 + O_2^- \rightarrow HO_2 + 2H_2O$	"	"				"
25.	$H^+(H_2O)_2 + O_2^-(H_2O) \rightarrow H + 3H_2O + O_2$	"	"				"
26.	$H^+(H_2O)_2 + O_3^- \rightarrow HO + 2H_2O + O_2$	"	"				"
27.	$H^+(H_2O)_2 + O_4^- \rightarrow HO_2 + 2H_2O + O_2$	"	"				"
28.	$H^+(H_2O)_2 + OONO^- \rightarrow HO_2 + 2H_2O + NO$	"	"				"
29.	$H^+(H_2O)_3 + CO_3^- \rightarrow CO_2 + HO + 3H_2O$	"	"				"
30.	$H^+(H_2O)_3 + CO_3^-(H_2O) \rightarrow CO_2 + H + 4H_2O + O$	"	"				"
31.	$H^+(H_2O)_3 + CO_4^- \rightarrow CO_2 + HO_2 + 3H_2O$	"	"				"
32.	$H^+(H_2O)_3 + CO_4^-(H_2O) \rightarrow CO_2 + H + 4H_2O + O_2$	"	"				"
33.	$H^+(H_2O)_3 + NO_2^- \rightarrow HO + 3H_2O + NO$	"	"				"
34.	$H^+(H_2O)_3 + NO_2^-(H_2O) \rightarrow H + 4H_2O + NO_2$	"	"				"
35.	$H^+(H_2O)_3 + NO_3^- \rightarrow HO + 3H_2O + NO_2$	"	"				"
36.	$H^+(H_2O)_3 + NO_3^-(H_2O) \rightarrow H + 4H_2O + NO_2 + O$	"	"				"
37.	$H^+(H_2O)_3 + O^- \rightarrow HO + 3H_2O$	"	"				"
38.	$H^+(H_2O)_3 + O_2^- \rightarrow HO_2 + 3H_2O$	"	"				"
39.	$H^+(H_2O)_3 + O_2^-(H_2O) \rightarrow H + 4H_2O + O_2$	"	"				"
40.	$H^+(H_2O)_3 + O_3^- \rightarrow HO + 3H_2O + O_2$	"	"				"

	Reactions	Code Values A	B	C	Remarks
41.	$H^+(H_2O)_3 + O_4^- \rightarrow HO_2 + 3H_2O + O_2$	2.0[-7]	-0.5		Estimated based on Smith et al., 1973
42.	$H^+(H_2O)_3 + OONO^- \rightarrow HO_2 + 3H_2O + NO$	"	"		"
43.	$H^+(H_2O)_4 + CO_3^- \rightarrow CO_2 + HO + 4H_2O$	"	"		"
44.	$H^+(H_2O)_4 + CO_3^-(H_2O) \rightarrow CO_2 + H + 5H_2O + O$	"	"		"
45.	$H^+(H_2O)_4 + CO_4^- \rightarrow CO_2 + HO_2 + 4H_2O$	"	"		"
46.	$H^+(H_2O)_4 + CO_4^-(H_2O) \rightarrow CO_2 + H + 5H_2O + O_2$	"	"		"
47.	$H^+(H_2O)_4 + NO_2^- \rightarrow HO + 4H_2O + NO$	"	"		"
48.	$H^+(H_2O)_4 + NO_2^-(H_2O) \rightarrow H + 5H_2O + NO_2$	"	"		"
49.	$H^+(H_2O)_4 + NO_3^- \rightarrow HO + 4H_2O + NO_2$	"	"		"
50.	$H^+(H_2O)_4 + NO_3^-(H_2O) \rightarrow H + 5H_2O + NO_2 + O$	"	"		"
51.	$H^+(H_2O)_4 + O^- \rightarrow HO + 4H_2O$	"	"		"
52.	$H^+(H_2O)_4 + O_2^- \rightarrow HO_2 + 4H_2O$	"	"		"
53.	$H^+(H_2O)_4 + O_2^-(H_2O) \rightarrow H + 5H_2O + O_2$	"	"		"
54.	$H^+(H_2O)_4 + O_3^- \rightarrow HO + 4H_2O + O_2$	"	"		"
55.	$H^+(H_2O)_4 + O_4^- \rightarrow HO_2 + 4H_2O + O_2$	"	"		"
56.	$H^+(H_2O)_4 + OONO^- \rightarrow HO_2 + 4H_2O + NO$	"	"		"
57.	$H^+(H_2O)_5 + CO_3^- \rightarrow CO_2 + HO + 5H_2O$	"	"		"
58.	$H^+(H_2O)_5 + CO_3^-(H_2O) \rightarrow CO_2 + H + 6H_2O + O$	"	"		"
59.	$H^+(H_2O)_5 + CO_4^- \rightarrow CO_2 + HO_2 + 5H_2O$	"	"		"
60.	$H^+(H_2O)_5 + CO_4^-(H_2O) \rightarrow CO_2 + H + 6H_2O + O_2$	"	"		"
61.	$H^+(H_2O)_5 + NO_2^- \rightarrow HO + 5H_2O + NO$	"	"		"
62.	$H^+(H_2O)_5 + NO_2^-(H_2O) \rightarrow H + 6H_2O + NO_2$	"	"		"
63.	$H^+(H_2O)_5 + NO_3^- \rightarrow HO + 5H_2O + NO_2$	"	"		"
64.	$H^+(H_2O)_5 + NO_3^-(H_2O) \rightarrow H + 6H_2O + NO_2 + O$	"	"		"

	Reactions			Code Values A	B	C	Reference Values	References	Remarks
65.	$H^+(H_2O)_5 + O^-$	→	$HO + 5H_2O$	2.0[-7]	-0.5				Estimated based on Smith et al., 1973
66.	$H^+(H_2O)_5 + O_2^-$	→	$HO_2 + 5H_2O$	"	"				"
67.	$H^+(H_2O)_5 + O_2^-(H_2O)$	→	$H + 6H_2O + O_2$	"	"				"
68.	$H^+(H_2O)_5 + O_3^-$	→	$HO + 5H_2O + O_2$	"	"				"
69.	$H^+(H_2O)_5 + O_4^-$	→	$HO_2 + 5H_2O + O_2$	"	"				"
70.	$H^+(H_2O)_5 + OONO^-$	→	$HO_2 + 5H_2O + NO$	"	"				"
71.	$NO^+ + CO_3^-$	→	$CO_2 + NO + O$	"	"				"
72.	$NO^+ + CO_3^-(H_2O)$	→	$CO_2 + H_2O + NO + O$	"	"				"
73.	$NO^+ + CO_4^-$	→	$CO_2 + NO + O_2$	"	"				"
74.	$NO^+ + CO_4^-(H_2O)$	→	$CO_2 + H_2O + NO + O_2$	"	"				"
75.	$NO^+ + NO_2^-$	→	$NO + NO_2$	3.5[-7]	"		$(3.5 \pm 2.0)[-7](T/300)^{-0.5}$	DNA 1948H, V-8	
							$(5.1 \pm 1.5)[-7]$	Peterson et al., 1971	Extrapolated to 300°K
							$(1.75 \pm 0.6)[-7]$	Eisner & Hirsh, 1971	300°K
76.	$NO^+ + NO_2^-(H_2O)$	→	$H_2O + NO + NO_2$	2.0[-7]	"				Estimated
77.	$NO^+ + NO_3^-$	→	$NO + NO_2 + O$	"	"		No recommendation	DNA 1948H, V-9	Estimated
							$(8.1 \pm 2.3)[-7]$	Aberth et al., 1971	Extrapolated to 300°K
							$(3.4 \pm 1.2)[-8]$	Eisner & Hirsh, 1971	300°K
78.	$NO^+ + NO_3^-(H_2O)$	→	$H_2O + NO + NO_2 + O$	"	"				Estimated
79.	$NO^+ + O^-$	→	$NO + O$	4.9[-7]	"		$(4.9 \pm 1.5)[-7](T/300)^{-0.5}$	DNA 1948H, V-7	
							$(4.9 \pm 2.0)[-7]$	Moseley et al., 197	Extrapolated to 300°K
80.	$NO^+ + O_2^-$	→	$NO + O_2$	5.8[-7]	"		$(5.8 \pm 1.0)[-7]$	Moseley, 1973	Extrapolated to 300°K
81.	$NO^+ + O_2^-(H_2O)$	→	$H_2O + NO + O_2$	2.0[-7]	"				Estimated
82.	$NO^+ + O_3^-$	→	$NO + O_3$	"	"				"
83.	$NO^+ + O_4^-$	→	$NO + 2O_2$	"	"				"
84.	$NO^+ + OONO^-$	→	$2NO + O_2$	"	"				"

Reactions				Code Values A	B	C	Reference Values	References	Remarks
85.	$O_2^+ + CO_3^-$	→	$CO_2 + O + O_2$	2.0[-7]	-0.5				Estimated
86.	$O_2^+ + CO_3^-(H_2O)$	→	$CO_2 + H_2O + O + O_2$	"	"				"
87.	$O_2^+ + CO_4^-$	→	$CO_2 + 2O_2$	"	"				"
88.	$O_2^+ + CO_4^-(H_2O)$	→	$CO_2 + H_2O + 2O_2$	"	"				"
89.	$O_2^+ + NO_2^-$	→	$NO_2 + O_2$	4.1[-7]	"		$(4.1 \pm 1.3)[-7](T/300)^{-0.5}$	DNA 1948H, V-4	
							$(4.1 \pm 1.3)[-7]$	Peterson et al., 1971	Extrapolated to 300°
90.	$O_2^+ + NO_2^-(H_2O)$	→	$H_2O + NO_2 + O_2$	2.0[-7]	"				Estimated
91.	$O_2^+ + NO_3^-$	→	$NO_2 + O + O_2$	1.3[-7]	"		$(1.3 \pm 0.5)[-7](T/300)^{-0.5}$	DNA 1948H, V-5	
							$(1.3 \pm 0.4)[-7]$	Aberth et al., 1971	Extrapolated to 300°K
92.	$O_2^+ + NO_3^-(H_2O)$	→	$H_2O + NO_2 + O + O_2$	2.0[-7]	"				Estimated
93.	$O_2^+ + O^-$	→	$O + O_2$	9.6[-8]	"		$(9.6 \pm 3.0)[-8](T/300)^{-0.5}$	DNA 1948H, V-2	Peterson (unpublished)
94.	$O_2^+ + O_2^-$	→	$2O_2$	4.2[-7]	"		$(4.2 \pm 1.3)[-7](T/300)^{-0.5}$	DNA 1948H, V-3	
							$(4.2 \pm 1.3)[-7]$	Peterson et al., 1971	Extrapolated to 300°K
95.	$O_2^+ + O_2^-(H_2O)$	→	$H_2O + 2O_2$	2.0[-7]	"				Estimated
96.	$O_2^+ + O_3^-$	→	$O_2 + O_3$	"	"				"
97.	$O_2^+ + O_4^-$	→	$3O_2$	"	"				"
98.	$O_2^+ + OONO^-$	→	$NO + 2O_2$	"	"				"
B.	Reactions Omitted from AIRCHEM								
1.	$H_3O^+(HO) + X^-$	→	Products	5.0[-8]	"				Estimated, X^- each of 14 negative ions
2.	$H_3O^+(N_2) + X^-$	→	Products	"	"				"
3.	$N^+ + NO_2^-$	→	$N + NO_2$	2.0[-7]	"				Estimated
4.	$N^+ + O^-$	→	$N + O$	2.6[-7]	"		$(2.6 \pm 0.8)[-7](T/300)^{-0.5}$	DNA 1948H, V-10	
							$(2.6 \pm 0.8)[-7]$	Peterson et al., 1971	Extrapolated to 300°K
5.	$N^+ + O_2^-$	→	$N + O_2$	2.0[-7]	"				Estimated

	Reactions	Code Values A	B	C	Reference Values	References	Remarks
6.	$N^+ + O_3^- \rightarrow N + O_3$	2.0[- 7]	-0.5				Estimated
7.	$NO^+ + O^- + M \rightarrow NO_2 + M$	2.0[-25]	-2.5				"
8.	$NO^+ + O_2^- + M \rightarrow NO + O_2 + M$	"	"				"
9.	$NO^+(CO_2) + X^- \rightarrow$ Products	1.0[- 7]	-0.5				Estimated, X^- each of 14 negative ions
10.	$NO^+(H_2O) + X^- \rightarrow$ Products	"	"				"
11.	$NO^+(H_2O)_2 + X^- \rightarrow$ Products	5.0[- 8]	"				"
12.	$NO^+(H_2O)_3 + X^- \rightarrow$ Products	3.0[- 8]	"				"
13.	$NO^+(N_2) + X^- \rightarrow$ Products	1.0[- 7]	"				"
14.	$NO_2^+ + X^- \rightarrow$ Products	"	"				"
15.	$N_2^+ + NO_2^- \rightarrow NO_2 + N_2$	"	"				Estimated
16.	$N_2^+ + O^- \rightarrow N_2 + O$	"	"				"
17.	$N_2^+ + O^- + M \rightarrow N_2O + M$	2.0[-25]	-2.5				"
18.	$N_2^+ + O_2^- \rightarrow N_2 + O_2$	1.6[- 7]	-0.5		$(1.6 \pm 0.5)[-7](T/300)^{-0.5}$ $(1.6 \pm 0.5)[-7]$	DNA 1948H, V-6 Peterson et al., 1971	Extrapolated to 300°K
19.	$N_2^+ + O_2^- + M \rightarrow N_2 + O_2 + M$	2.0[-25]	-2.5				Estimated
20.	$N_2^+ + O_3^- \rightarrow N_2 + O_3$	1.0[- 7]	-0.5				"
21.	$O^+ + NO_2^- \rightarrow NO_2 + O$	"	"				"
22.	$O^+ + O^- \rightarrow O + O$	2.7[- 7]	"		$(2.7 \pm 1.3)[-7](T/300)^{-0.5}$ $(2.7 \pm 1.3)[-7]$	DNA 1948H, V-1 Peterson et al., 1971	Extrapolated to 300°K
23.	$O^+ + O^- + M \rightarrow O_2 + M$	2.0[-25]	-2.5				Estimated
24.	$O^+ + O_2^- \rightarrow O + O_2$	1.0[- 7]	-0.5				Estimated
25.	$O^+ + O_2^- + M \rightarrow O_3 + M$	2.0[-25]	-2.5				"
26.	$O^+ + O_3^- \rightarrow O + O_3$	1.0[- 7]	-0.5				"
27.	$O_2^+ + O^- + M \rightarrow O_3 + M$	2.0[-25]	-2.5				"
28.	$O_2^+ + O_2^- + M \rightarrow 2O_2 + M$	"	"				"

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FOR
TABLE VII

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TABLE VIII

Neutral-Neutral Reactions and De-excitation Reactions

$k = A(T/300)^B \exp(-C/T)$

Two-body reactions in units of cm^3 $molecule^{-1}$ s^{-1} Three-body reactions in units of cm^6 $molecule^{-1}$ s^{-1}

De-excitation frequency in units of s^{-1}

A. Reactions in AIRCHEM

Reactions	Code Value A	B	C	Reference Values	References	Remarks
1. $N(^2D) + O_2 \rightarrow NO + O$	7.0[-12]*	-0.5		$7[-12](T/300)^{-0.5}$	DNA 1948H, XXVII-13	
				$(6 \pm 2)[-12]$	Lin & Kaufman, 1971	
				1.4[-11]	Black, 1973	
2. $O(^1D) \rightarrow O + h\nu$	6.8[-3]			$(6.8 \pm 2.0)[-3]$	DNA 1948H, XXVIII-1	
3. $O(^1D) + H_2 \rightarrow H + HO$	2.9[-10]			$3.5[-10 \pm 1]$	DNA 1948H, XXVII-8	
				$(2.9\ ^{+0.7}_{-0.6})[-10]$	Garvin, 1973a	
4. $O(^1D) + H_2O \rightarrow 2HO$	3.5[-10]			$(2 \pm 1)[-10]$	DNA 1948H, XXVII-11	
				$(3\ ^{+3}_{-1.5})[-10]$	Hampson et al., 1972b	
				1.4[-10]	Schofield, 1967	
				$(3.5\ ^{+0.9}_{-0.7})[-10]$	Hampson et al., 1973	300°K
5. $O(^1D) + N_2 + M \rightarrow N_2O + M$	2.8[-36]			~5[-36] ± factor of 50	Schofield, 1973	M = N_2, 300°K
				2.8[-36]	Garvin, 1973a	
6. $O(^1D) + N_2O \rightarrow 2NO$	1.1[-10]			$(1\ ^{+1}_{-0.5})[-10]$	Hampson et al., 1972b	300°K
				$(1.1\ ^{+0.3}_{-0.2})[-10]$	Hampson et al., 1973	300°K

*Read 7.0[-12] as 7.0×10^{-12}

Reactions	Code Value A	B	C	Reference Values	References	Remarks
7. $O(^1D) + O_2 \rightarrow O_2(^1\Sigma) + O$	7.5[-11]			(7 ± 2)[-11]	DNA 1948H, XXX-3	
				6[-11]	Noxon, 1970	
				$(7.5\ ^{+1.9}_{-1.5})$[-11]	Garvin, 1973a	298°K
8. $O(^1D) + O_3 \rightarrow 2O_2$	2.5[-10]			(2.5 ± 1.0)[-10]	DNA 1948H, XXVII-7	
				(2.5 ± 1.0)[-10]	Gilpin et al., 1971	
				$(5.0\ ^{+5.0}_{-2.5})$[-10]	Garvin, 1973a	Sum for two equal channels
9. $O(^1D) + M \rightarrow O + M$	5.5[-11]			(8.0 ± 4.0)[-11]	DNA 1948H, XXX-2	M = N_2
				(5 ± 4)[-11]	Schiff, 1972	M = N_2
				5[-11]	Young et al., 1968	M = N_2
				9[-11]	Noxon, 1970	M = N_2
				5[-11]	Gilpin et al., 1971	M = O_2
				(6.9 ± 0.6)[-11]	Heidner et al., 1973	M = N_2
				(5.5 ± 1.5)[-11]	Garvin, 1973b	M = N_2
10. $O_2(^1\Delta) \rightarrow O_2 + h\nu$	2.6[-4]			(2.6 ± 1.0)[-4]	DNA 1948H, XXVIII-5	
11. $O_2(^1\Delta) + O_2(^1\Delta) \rightarrow O_2(^1\Sigma) + O_2$	2.0[-18]			2[-18 ± 1]	DNA 1948H, XXX-20	
12. $O_2(^1\Delta) + O_2 \rightarrow 2O_2$	2.2[-18]	0.8		(2.4 ± 0.2)[-18]	DNA 1948H, XXX-17	
				$(2.2 \pm 0.5)[-18](T/300)^{0.8}$	Hampson et al., 1972b	285-322°K
				$(2.22 \pm 0.09)[-18](T/300)^{0.78 \pm 0.32}$	Findlay & Snelling, 1971	
				$(2.2\ ^{+0.6}_{-0.4})[-18](T/300)^{0.8}$	Garvin et al., 1973a	285-322°K
13. $O_2(^1\Sigma) \rightarrow O_2 + h\nu$	8.3[-2]			8.3[-2 ± 0.3]	DNA 1948H, XXVIII-6	
14. $O_2(^1\Sigma) + O_3 \rightarrow O + 2O_2$	2.5[-11]			6[-13 ± 1]	DNA 1948H, XXVI-7	
				(2.5 ± 0.5)[-11]	Gilpin et al., 1971	
15. $O_2(^1\Sigma) + M \rightarrow O_2 + M$	2.0[-15]			(2.0 ± 1.0)[-15]	DNA 1948H, XXX-22	M = N_2
				2[-15]	Noxon, 1970	M = N_2
				(2.0 ± 0.5)[-15]	Hampson et al., 1972a	M = N_2
				(1.5 ± 0.5)[-16]	Hampson et al., 1972a	M = O_2
				(4 ± 2)[-12]	Hampson et al., 1972a	M = H_2O

Reactions	Code Value A	B	C	Reference Values	References	Remarks
16. $CO + HO \rightarrow CO_2 + H$	1.3[-13]			7[-13]exp(-540/T)	DNA 1948H, XXVII-31	
				1.1[-12]exp(-518/T)	Schofield, 1967	300-2000°K
				(9.3 ± 1.3)[-13]exp(-540 ± 250/T)	Baulch et al., No. 1, 1968	
				(6.46 ± 1.17)[-13]exp(-408 ± 65/T)	Kondratiev, 1970	300-1700°K
				5.1[-13]exp(-300/T)	Wilson, 1972	300-2000°K
				$(1.33\ ^{+0.34}_{-0.27})$[-13]	Garvin, 1973a	200-400°K
17. $CO + O + M \rightarrow CO_2 + M$	6.5[-33]		2170	(1.4 ± 0.3)[-35]	DNA 1948H, XXV-14	M = N_2
				6.5[-33]exp(-2170 ± 225/T)	Slanger et al., 1972a	M = CO; 250-350°K
				2.3[-36]	Slanger et al., 1972a	M = N_2; 296°K
				6.2[-36]	Slanger et al., 1972a	M = CO_2; 296°K
					Baulch et al., No. 1, 1968	No recommendation
18. $H + H + M \rightarrow H_2 + M$	8.3[-33]			$8.3[-33 \pm 0.5](T/300)^{-0.6 \pm 0.2}$	DNA 1948H, XXV-11	
				(8.3 ± 4.2)[-33]	Baulch et al., 1972	M = H_2; 300°K
19. $H + HO \rightarrow H_2 + O$	4.2[-12]	1.0	3500	1.2[-11]exp(-3650/T)	DNA 1948H, XXVII-22	
				9.3[-12]exp(-3790/T)	Schofield, 1967	400-2500°K
				1.8[-11]exp(-4011/T)	Kondratiev, 1970	370-1700°K
				9[-12]exp(-3700 ± 300/T)	Bascombe, 1965	300-3000°K
				(1.2 ± 0.4)[-11]exp(-3650/T)	Baulch et al., No. 2, 1968	400-3000°K
				$(2.2\ ^{+2.2}_{-1.1})$[-11]exp(-4051/T)	Wilson, 1972	500-3000°K
				(1.4 ± 0.4)[-14]Texp(-3500/T)	Baulch et al., 1972	400-2000°K
				(1.4 ± 0.4)[-14]Texp(-3500/T)	Garvin, 1973a	400-2000°K
20. $H + HO + M \rightarrow H_2O + M$	4.3[-30]	-2.0		(7 ± 4)[-32]	DNA 1948H, XXV-13	2000°K
				$(3.9\ ^{+2.0}_{-1.3})$[-25] T^{-2}	Baulch et al., 1972	M = H_2O; 1000-3000°K
				$(4.1\ ^{+8.2}_{-2.8})$[-23] $T^{-2.6}$	Wilson, 1972	M = H_2O; 1000-3300°K
				$(2.1\ ^{+4.2}_{-1.4})$[-24] $T^{-2.6}$	Wilson, 1972	M = Ar; 1000-3300°K
				1.41[-31]	Garvin & Gevantman, 1972	M = CO_2; 2000°K
				$5[-24]T^{-2.43}$	Kondratiev, 1970	M = N_2; 1100-2000°K
				$(3.9\ ^{+3.9}_{-2.0})$[-25] T^{-2}	Garvin, 1973a	M = N_2; 1000-3000°K

Reactions	Code Value A	B	C	Reference Values	References	Remarks
21a. $H + HO_2 \rightarrow 2HO$	4.2[-10]		950	$\geq$ 1[-11]	DNA 1948H, XXVII-23a	
				$(4.2\ ^{+4.2}_{-2.1})$[-10]exp(-950/T)	Baulch et al., 1972	290-800°K
				$(4.2\ ^{+4.2}_{-2.1})$[-10]exp(-950/T)	Garvin, 1973a	290-800°K
				2.8[-10]exp(-1010/T)	Kondratiev, 1970	300-780°K
				1.6[-10]exp(-900/T)	Lloyd, 1970	300-1000°K
21b. $H + HO_2 \rightarrow H_2 + O_2$	4.2[-11]		350	$\geq$ 3[-12]	DNA 1948H, XXVII-23b	
				$(4.2\ ^{+6.3}_{-2.5})$[-11]exp(-350/T)	Baulch et al., 1972	290-800°K
				$(4.2\ ^{+6.3}_{-2.5})$[-11]exp(-350/T)	Garvin, 1973a	290-800°K
				3.16[-11 ± 1]exp(-500/T)	Lloyd, 1970	
21c. $H + HO_2 \rightarrow H_2O + O$	1.6[-11]		500	1.58[-11 ± 1]exp(-500/T)	Lloyd, 1970	
					Baulch et al., 1972	No recommendation
					Schofield, 1967	Much slower than 21a & 21b
22a. $H + H_2O_2 \rightarrow HO + H_2O$	5.3[-10]		4500	5.3[-10]exp(-4500/T)	Baulch et al., No.3,1969	500-1000°K
					Baulch et al., 1972	No recommendation
					Hampson et al., 1973	No recommendation
22b. $H + H_2O_2 \rightarrow HO_2 + H_2$	2.8[-12]		1900	3.9[-11]exp(-4600/T)	DNA 1948H, XXVII-24	
				$(2.8\ ^{+2.8}_{-1.4})$[-12]exp(-1900/T)	Baulch et al., 1972	300-800°K
				$(2.8\ ^{+2.8}_{-1.4})$[-12]exp(-1900/T)	Hampson et al., 1973	300-800°K
				3.9[-11]exp(-4600/T)	Baulch et al., No.3,1969	500-1500°K
23. $H + NO_2 \rightarrow HO + NO$	5.8[-10]		740	8.91[-10]exp(-876/T)	Kondratiev, 1970	500-630°K
				1.2[-9]exp(-971/T)	Schofield, 1967	298-633°K
				(4.8 ± 1.2)[-11]	Hampson et al., 1972a	298°K; M = Ar, He
				$(5.8\ ^{+3.4}_{-2.1})$[-10]exp(-740/T)	Garvin, 1973b	298-633°K
24. $H + N_2O \rightarrow HO + N_2$	1.3[-10]		7600	$(1.5^{+0.9}_{-0.6})$[-10]exp(-6810 ± 730/T)	Kondratiev, 1970	420-1800°K
				4.9[-11]exp(-5420/T)	Schofield, 1967	400-2000°K
				$(1.26\ ^{+0.73}_{-0.46})$[-10]exp(-7600/T)	Garvin, 1973a	700-2500°K
25. $H + O + M \rightarrow HO + M$	2.0[-32]			2.0[-32]	Schofield, 1967	M = Ar, H_2O, O_2; 1000-3000°K
				$\sim$ 2[-32 ± 1]	Schofield, 1973	M = Ar; 1000-3000°K
					Baulch et al., 1972	No recommendation

	Reactions	Code Value A	B	C	Reference Values	References	Remarks
26.	$H + O_2 + M \rightarrow HO_2 + M$	2.1[-32]		-290	$(9 \pm 2)[-33]\exp(-500 \pm 300/T)$	DNA 1948H, XXV-12	Exp should be +500
					$(4.1 \pm 2.1)[-33]\exp(500/T)$	Baulch et al., 1972	M = He,Ar; 300-2000°K
					$(3.4\ ^{+7.5}_{-2.4})[-29]\ T^{-1.24 \pm 0.19}$	Kondratiev, 1970	M = Ar; 290-1500°K
					$(6.75 \pm 1.1)[-33]\exp(345 \pm 64/T)$	Davis et al., 1972c	M = Ar; 220-360°K $k_{Ar}:k_{He}:k_{H_2}:k_{N_2}$ = 1.0:0.97:3.02:2.8
					$(2.1 \pm 0.3)[-32]\exp(290/T)$	Garvin, 1973a	M = N_2; 203-404°K
27.	$H + O_3 \rightarrow HO + O_2$	2.6[-11]			2.6[-11]	DNA 1948H, XXVII-21a	Products also $HO_2 + O$
					$(2.6 \pm 0.7)[-11]$	Hampson et al., 1972a	298 K
					2.57[-11]	Schofield, 1967	
					$(2.6\ ^{+0.7}_{-0.5})[-11]$	Garvin, 1973a	300°K
28.	$HNO_2 + HO \rightarrow H_2O + NO_2$	6.8[-12]					
						Hampson et al., 1972a	No data
						Hampson et al., 1973	No recommendation
					6.8[-12]	Garvin, 1973a	Estimated; no data
29.	$HNO_3 + HO \rightarrow H_2O + NO_2 + O$	6.0[-13]		400	$(1.4\ ^{+2.8}_{-0.9})[-12]\exp(-1000/T)$	Garvin & Hampson, 1972	300-650°K
					$(1.7 \pm 0.2)[-13]$	Wilson, 1972	300°K
					$(1.3 \pm 0.5)[-13]$	Marley & Smith, 1972	300°K
					$(6\ ^{+12}_{-4})[-13]\exp(-400/T)$	Hampson et al., 1973	300-650°K; NO_3 given as products
30.	$HO + HO \rightarrow H_2O + O$	1.0[-11]		550	5[-11]exp(-400/T)	DNA 1948H, XXVII-26	
					$(1.0\ ^{+0.5}_{-0.3})[-11]\exp(-550/T)$	Baulch et al., 1972	300-2000°K
					$(1.3\ ^{+0.7}_{-0.4})[-11]\ \exp(-705 \pm 180/T)$	Kondratiev, 1970	300-2400°K
					$(2.57\ ^{+0.67}_{-1.76})[-12]$	Wilson, 1972	300°K
					1.38[-11]exp (-503/T)	Schofield, 1967	300°K
					$(1.0\ ^{+0.6}_{-0.4})[-11]\exp(-550/T)$	Garvin, 1973a	300-2000°K
31.	$HO + HO + M \rightarrow H_2O_2 + M$	2.3[-33]		-2650	$(2.3\ ^{+4.4}_{-1.6})[-33]\exp(2650/T)$	Wilson, 1972	M = N_2; 500-1000°K
					$(2.5 \pm 0.6)[-33]\exp(2550/T)$	Baulch et al., 1972	M = N_2; 700-1500°K

Reactions	Code Value A	B	C	Reference Values	References	Remarks
32. $HO + HO_2 \rightarrow H_2O + O_2$	1.6[-11]		500	$\geq$ 1[-11]	DNA 1948H, XXVII-28	
				1.58[-11 $\pm$ 1]exp(-500/T)	Lloyd, 1970	300-1000°K
				(2.0 $\pm$ 0.3)[-10]	Hochanadel et al., 1972	298°K
				2.0[-11]	Friswell & Sutton, 1972	2130°K
					Baulch et al., 1972	No recommendation
				2[-10.5 $\pm$ 0.5]	Garvin, 1973a	
33. $HO + H_2 \rightarrow H + H_2O$	3.6[-11]		2590	3.6[-11]exp(-2580/T)	DNA 1948H, XXVII-27	
				(3.6 $\pm$ 0.7)[-11]exp(-2590/T)	Baulch et al., 1972	300-2500°K
				6.3[-11]exp(-2763/T)	Schofield, 1967	300-2500°K
				$(3.8\ ^{+3.8}_{-1.9})$[-11]exp(-2600/T)	Wilson, 1972	300-2000°K
34. $HO + H_2O_2 \rightarrow HO_2 + H_2O$	1.7[-11]		910	2[-11]exp(-900/T)	DNA 1948H, XXVII-29	
				(1.7 $\pm$ 0.8)[-11]exp(-910/T)	Baulch et al., 1972	300-800°K
				1.3[-11]exp(-810/T)	Kondratiev, 1970	300-800°K
				$(1.7\ ^{+1.0}_{-0.6})$exp(-910/T)	Garvin & Hampson, 1972	300-800°K
				(1.7 $\pm$ 0.9)[-11]exp(-910/T)	Hampson et al., 1973	300-800°K
35. $HO + N \rightarrow H + NO$	5.3[-11]			5.81[-11]	Wilson, 1970	320°K
				$(5.3\ ^{+5.3}_{-2.7})$[-11]	Garvin, 1973b	300°K
36. $HO + NO_2 + M \rightarrow HNO_3 + M$	2.0[-30]			(2.0 $\pm$ 0.5)[-30]	Anderson & Kaufman, 1972b	M = N_2; 297°K
				(1.0 $\pm$ 0.3)[-30]	Anderson & Kaufman, 1972b	M = Ar; 297°K
					Hampson et al., 1973	Perferred values plotted over altitude range 15-45 km for effective two-body rate coefficient
				(1.4 to 32)[-13]	Garvin, 1973a	
37a. $HO + O \rightarrow H + O_2$	4.2[-11]			(5 $\pm$ 2)[-11]	DNA 1948H, XXVII-9	
				(3.8 $\pm$ 1.6)[-11]	Baulch et al., 1972	300°K
				$(2.2\ ^{+2.2}_{-1.1})$[-11]	Baulch et al., No.3,1969	300-1500°K
				2.06[-11]	Schofield, 1967	300-900°K
				(4.15 $\pm$ 1.66)[-11]	Wilson, 1972	300-2000°K
				(4.2 $\pm$ 1.7)[-11]	Garvin, 1973a	300-1000°K

	Reactions	Code Value A	B	C	Reference Values	References	Remarks
37b.	$H + O_2 \rightarrow HO + O$	3.7[-10]		8450	(3.7 ± 1.1)[-10]exp(-8450/T)	Baulch et al., 1972	700-2500°K
					(3.7 ± 1.9)[-10]exp(-8400/T)	Baulch et al.,No.3, 1969	300-3000°K
					4.19[-10]exp(-8450/T)	Schofield, 1967	300-2500°K
38.	$HO + O + M \rightarrow HO_2 + M$	1.0[-31]					Estimated
						Baulch et al., 1972	No recommendation
39.	$HO + O_3 \rightarrow HO_2 + O_2$	1.6[-12]		1000	> 5[-13]	DNA 1948H, XXVII-25	
					1.3[-12]exp(-956/T)	Anderson & Kaufman,1973	220-450°K
					8[-14]	DeMore, 1973	300°K
					$(1.6\ ^{+1.6}_{-0.8})$[-12]exp(-1000/T)	Hampson et al., 1973	220-450°K
40.	$HO_2 + HO_2 \rightarrow H_2O_2 + O_2$	3.0[-11]		500	3[-12]	DNA 1948H, XXVII-30	
					1.7[-11]exp(-500K)	Hampson et al., 1972b	300-1000°K
					$(1.6\ ^{+4.4}_{-1.1})$[-11]exp(-500/T)	Lloyd, 1970	300-1000°K
					$(3\ ^{+3}_{-1.5})$[-11]exp(-500/T)	Garvin & Hampson, 1972	300-1000°K
					(3.3 ± 0.7)[-12]	Baulch et al., 1972	300°K
					(9.5 ± 0.8)[-12]	Hochanadel et al., 1972	298°K
					$(3\ ^{+3}_{-1.5})$[-11]exp(-500/T)	Hampson et al., 1973	300-1000°K
41.	$HO_2 + NO \rightarrow HO + NO_2$	2.0[-13]			$(3\ ^{+6}_{-3})$[-13]	Davis et al., 1972a	300°K
					1.6[-15 ± 1]	Lloyd, 1970	300-1000°K
					$(2\ ^{+4}_{-1.4})$[-13]	Garvin, 1973a	
42.	$HO_2 + O \rightarrow HO + O_2$	7.9[-11]		500	1[-11]	DNA 1948H, XXVII-10	
					7.9[-11 ± 1]exp(-500/T)	Lloyd, 1970	300-1000°K
43.	$HO_2 + O_3 \rightarrow HO + 2O_2$	1.0[-13]		1250	< 1.3[-12]exp(-956/T)	Anderson & Kaufman,1973	220-450°K
					3[-15]	DeMore, 1973	300°K
					3.3[-14]exp(-1006/T)	Simonaitis & Heicklen,1973	
					$(1\ ^{+1}_{-0.5})$[-13]exp(-1250/T)	Garvin, 1973a	225-298°K
44.	$H_2O_2 + NO_2 \rightarrow HNO_3 + HO$	1.0[-18]			< 1[-18]	Gray et al., 1972	298°K

	Reactions	Code Value A	B	C	Reference Values	References	Remarks
45.	$H_2O_2 + O \rightarrow HO + HO_2$	5.6[-11]		2950			Estimated
						Baulch et al., 1972	No recommendation
					(3.6 ± 0.6)[-11]exp(-2950/T)	Garvin, 1973	283-373°K; Sum of two channels
46.	$N + N + M \rightarrow N_2 + M$	8.3[-34]		-500	(7.6 ± 2.0)[-34]exp(-500 ± 200/T)	DNA 1948H, XXV-4a	Exp should be +500
					7[-34]exp(500/T)	Clyne & Stednan, 1967	M = N_2; 90-600°K
					$(8.3\ ^{+5.0}_{-3.1})$[-34]exp(500/T)	Garvin, 1973b	M = N_2; 100-600°K
47a.	$N + NO \rightarrow N_2 + O$	1.4[-11]			(2.2 ± 0.6)[-11]	DNA 1948H, XXVII-15	N_2(v=3-6); Two channels
					4.57[-11]exp(-250/T)	Kondratiev, 1970	300-1900°K
					$(5.1\ ^{+5.1}_{-2.6})$[-11]exp(-167/T)	Baulch et al., No.4,1969	300-1600°K
					$(2.7\ ^{+0.7}_{-0.6})$[-11]	Garvin, 1973b	300-5000°K
47b.	$N + NO \rightarrow O(^1D) + N_2$	1.4[-11]					Estimated
48a.	$N + NO_2 \rightarrow 2NO$	9.0[-12]			(6 ± 1)[-12]	DNA 1948H, XXVII-16b	One of four channels
					6[-12]	Phillips & Schiff, 1965	300°K
						Baulch et al., No.4,1969	No recommendation
						Garvin, 1973	No recommendation
48b.	$N + NO_2 \rightarrow N_2O + O$	9.0[-12]			(8 ± 1)[-12]	DNA 1948H, XXVII-16a	One of four channels
					8[-12]	Phillips & Schiff, 1965	300°K
						Baulch et al., No.4,1969	No recommendation
49.	$N + O + M \rightarrow NO + M$	1.1[-32]	-0.5		$(1.1 \pm 0.3)[-32](T/300)^{-0.5 \pm 0.2}$	DNA 1948H, XXV-5	M = N_2
					$(1.1 \pm 0.5)[-32](T/273)^{-0.5}$	Baulch et al., No.4, 1969	M = N_2; 200-400°K
					$(1.8\ ^{+1.1}_{-0.7})$[-31] $T^{-0.5}$	Garvin, 1973b	M = N_2; 200-400°K
50.	$N + O_2 \rightarrow NO + O$	3.3[-12]	1.0	3150	(2.4 ± 0.3)[-11]exp(-4000 ± 200/T)	DNA 1948H, XXVII-12	
					(1.7 ± 0.3)[-11]exp(-3770 ± 100/T)	Kondratiev, 1970	300-3200°K
					(1.1 ± 0.3)[-14]Texp(-3125/T)	Baulch et al., No.4,1969	300-2000°K
					$(1.0\ ^{+1.0}_{-0.5})$[-14]Texp(-3390/T)	Wilson & Garvin, 1968	300-5000°K
					2.46[-16]$T^{1.5}$exp(-2860/T)	Schofield, 1967	400-5000°K
					$(1.1\ ^{+0.4}_{-0.3})$[-14]Texp(-3150/T)	Garvin, 1973b	300-3000°K

	Reactions	Code Value A	B	C	Reference Values	References	Remarks
51.	$N + O_3 \rightarrow NO + O_2$	3.4[-11]	0.5	1200	$3.4[-11](T/300)^{0.5}\exp(-1200/T)$	DNA 1948H, XXVII-17	
					$(5.7 \pm 1.4)[-13]$	Phillips & Schiff, 1962	300°K
					$(5.7\ ^{+3.3}_{-2.1})[-13]$	Garvin, 1973b	298°K
52.	$NO + NO + O_2 \rightarrow 2NO_2$	3.3[-39]		-526	$1.1[-38]\exp(-480/T)$	DNA 1948H, XXVII-19	$-d[NO]/dt = 2k[NO]^2[O_2]$
					$(3.2\ ^{+1.6}_{-1.0})[-39]\exp(670 \pm 110/T)$	Kondratiev, 1970	
					$(6.6 \pm 3.3)[-39]\exp(526 \pm 100/T)$	Baulch et al., No.5,1970	273-660°K
							$-d[NO]/dt = k[NO]^2[O_2]$
53.	$NO + O \rightarrow NO_2 + h\nu$	6.6[-17]	-1.9		$(6.2 \pm 1.0)[-17](T/300)^{-2.0 \pm 0.5}$	DNA 1948H, XXIII-3	
					$4.28[-17](T/300)^{-2.01}$	Kondratiev, 1970	200-3800°K
					$(6.6\ ^{+6.6}_{-3.3})[-17](T/300)^{-1.94}$	Baulch et al., No.5,1970	230-3750°K
					$(1.03 \pm 0.09)[-16]$	Golde et al., 1973	295°K
54.	$NO + O + M \rightarrow NO_2 + M$	4.1[-33]		-940	$(1.0 \pm 0.1)[-31](T/300)^{-2.5 \pm 0.3}$	DNA 1948H, XXV-10	$M = N_2$
					$(2.9 \pm 0.6)[-33]\exp(935/T)$	Baulch et al.,No.5,1970	$M = Ar, O_2$; 200-500°K
					$(7.4\ ^{+5.1}_{-3.0})[-27]T^{-2.04 \pm 0.09}$	Kondratiev, 1970	$M = O_2$; 200-2300°K
					$4[-33]\exp(970/T)$	Schofield, 1967	$M = N_2$; 300-500°K
					$(4.1 \pm 0.8)[-33]\exp(940/T)$	Hampson et al., 1973	$M = N_2$; 200-500°K
55.	$NO + O_3 \rightarrow NO_2 + O_2$	1.5[-12]		1330	$(9.5 \pm 1.0)[-13]\exp(-1300 \pm 100/T)$	DNA 1948H, XXVII-18	
					$(9 \pm 3)[-13]\exp(-1200/T)$	Hampson et al.,1972b	198-330°K
					$(1.1\ ^{+0.5}_{-0.3})[-12]\exp(-1233 \pm 86/T)$	Kondratiev, 1970	200-320°K
					$(1.5\ ^{+0.9}_{-0.6})[-12]\exp(-1330/T)$	Garvin, 1973b	200-350°K
56.	$NO_2 + O \rightarrow NO + O_2$	9.1[-12]			$(1.6 \pm 0.5)[-11]\exp(-300 \pm 150/T)$	DNA 1948H, XXVII-3	
					$(1.7 \pm 0.3)[-11]\exp(-300/T)$	Baulch et al., No.5,1970	280-550°K
					$(3.2\ ^{+5.9}_{-2.1})[-11]\exp(580 \pm 320/T)$	Kondratiev, 1970	900-2300°K
					$3.2[-11]\exp(-533/T)$	Schofield, 1967	278-374°K
					$(9.12 \pm 0.44)[-12]$	Davis et al., 1972b	230-339°K
					$(6.1 \pm 0.6)[-12]$	Clyne & Cruse, 1972	298°K
					$9.2[-12]$	Slanger et al., 1972b	296°K
					$10.5[-12]$	Slanger et al., 1972b	240°K
					$(9.1 \pm 1.8)[-12]$	Hampson et al., 1973	220-500°K

Reactions	Code Value A	B	C	Reference Values	References	Remarks
57. $O + O + M \rightarrow O_2 + M$	1.3[-32]	-1.0	170	$3.0[-33](T/300)^{-2.9 \pm 0.4}$	DNA 1948H, XXV-3a	$M = N_2$
				$(7.1\ ^{+8.0}_{-3.8})[-31]T^{-0.93 \pm 0.10}$	Kondratiev, 1970	$M = N_2$; 300-7500°K
				$6.2(-32)\exp(-750/T)$	Skinger et al., 1972a	$M = O$
				$(3.8\ ^{+3.8}_{-1.9})[-30]T^{-1}\exp(-170/T)$	Garvin, 1973a	$M = O_2$; 1000-8000°K
58. $O + O_2 + M \rightarrow O_3 + M$	1.1[-34]		-510	$(5.5 \pm 2.0)[-34](T/300)^{-2.6 \pm 0.4}$	DNA 1948H, XXV-8	$M = N_2$
				$(6.57 \pm 0.59)[-35]\exp(510 \pm 23/T)$	Davis et al., 1972c	$M = Ar$; 200-346°K $k_{Ar}:k_{He}:k_{N_2}$ = 1.0:0.92:1.6
				$(6.19 \pm 0.50)[-35]\exp(520 \pm 19/T)$	Huie et al., 1972	$M = Ar$; 200-346°K
				$(2.0\ ^{+1.2}_{-0.7})[-35]\exp(1050/T)$	Johnston, 1968	$M = N_2$, O_2; 200-1000°K
				$2.3[-35]\exp(1009/T)$	Schofield, 1967	$M = O_2$; 188-900°K
				$2.1[-35]\exp(1009/T)$	Schofield, 1967	$M = N_2$; 188-900°K
				$5.4[-34]$	Stuhl & Niki, 1971	$M = N_2$; 300°K
				$(7.0 \pm 1.0)[-34]$	Slanger & Black, 1970	$M = N_2$; 300°K
				$(1.06\ ^{+0.18}_{-0.16})[-34]\exp(510/T)$	Garvin, 1973a	$M = N_2$; 200-346°K
59a. $O + O_3 \rightarrow O_2(^1\Delta) + O_2$	1.0[-11]		2300	$4.5[-15 \pm 2]$	DNA 1948H, XXVII-6b	
59b. $O + O_3 \rightarrow 2O_2$	1.0[-11]		2300	$(1.4 \pm 0.3)[-11]\exp(-2220 \pm 200/T)$	DNA 1948H, XXVII-6a	
				$(2.0\ ^{+1.2}_{-0.7})[-11]\exp(-2410/T)$	Hampson et al., 1972b	200-1000°K
				$(6.2\ ^{+9.3}_{-3.7})[-12]\exp(-1880 \pm 310/T)$	Kondratiev, 1970	190-910°K
				$(1.05 \pm 0.18)[-11]\exp(-2155 \pm 50/T)$	McCrumb & Kaufman 1972	269-409°K
				$1.2[-11]\exp(-2150/T)$	Krezenski et al., 1971	197-299°K
				$(2.0 \pm 0.8)[-11]\exp(-2276 \pm 75/T)$	Davis et al., 1972a	220-355°K
				$(1.9\ ^{+0.5}_{-0.4})[-11]\exp(-2300/T)$	Hampson et al., 1973	200-1000°K

B. Reactions Omitted from AIRCHEM

1. $e + O_2(^1\Delta) \rightarrow e + O_2$	$1[-11 \pm 1]$	DNA 1948H, XXX-15	VIII A 12 more likely
2. $N(^2D) + NO \rightarrow N_2 + O$	$6.0[-11]$		Estimated

Reactions	Reference Values	References	Remarks
3. $N(^2D) + M \rightarrow N + M$	$(3 \pm 3)[-15]$	DNA 1948H, XXX-14	M = N_2; Reaction with O_2 more likely
4. $O(^1D) + H_2O_2 \rightarrow HO + HO_2$	$> 3[-10]$	Garvin, 1973a	
5. $O(^1D) + NO_2 \rightarrow NO + O_2$	$(2.8\ ^{+0.7}_{-0.6})[-10]$	Garvin, 1973a	
6. $O(^1D) + N_2O \rightarrow N_2 + O_2$	$(1\ ^{+1}_{-0.5})[-10]$	Hampson et al., 1972b	300°K; other channel is VIII A 6
	$(1.1\ ^{+0.3}_{-0.2})[-10]$	Hampson et al., 1973	300°K
7. $O(^1D) + O_2 \rightarrow O_2(^1\Delta) + O$	$1.0[-12]$		Estimated; Other channel is VIII A 7
8. $O_2(^1\Delta) + N \rightarrow NO + O$	$(2.0 \pm 0.8)[-14]\exp(-600/T)$	DNA 1948H, XXVII-14	VIII A 12 more likely
9. $O_2(^1\Delta) + N_2 \rightarrow N_2 + O_2$	$< 1.1[-19]$	DNA 1948H, XXX-19	VIII A 12 more likely
	$\leq 1[-19]$	Hampson et al., 1972b	
	$< 2[-20]$	Hampson et al., 1973	300°K
10. $O_2(^1\Delta) + O \rightarrow O + O_2$	$\leq 1[-16]$	DNA 1948H, XXX-16	VIII A 12 more likely
11. $O_2(^1\Delta) + O_3 \rightarrow O_2 + O_3$	$(3 \pm 2)[-15]$	DNA 1948H, XXX-18	VIII A 12 more likely
	$4.55[-11]\exp(-2810 \pm 180/T)$	Findlay & Snelling, 1971	
	$2.8[-15]$	Wayne & Pitts, 1969	
12. $CO + HO_2 \rightarrow CO_2 + HO$	$1.58[-12 \pm 1]\exp(-8300/T)$	Lloyd, 1970	
	$< 1[-20]$	Davis et al., 1972c	
13. $H + HNO_2 \rightarrow H_2 + NO_2$		Hampson et al., 1972a	No data
14. $H + HNO_3 \rightarrow$ products	$< 1[-13]$	Hampson et al., 1972a	
15. $H + H_2O \rightarrow HO + H_2$	$(1.5 \pm 0.8)[-10]\exp(-10250/T)$	Baulch et al., 1972	300-2500°K; Reverse of VIII A 33
	$(1.4 \pm 0.5)[-10]\exp(-10050/T)$	Baulch et al., No. 2, 1968	300-3000°K
	$3[-10]\exp(-10400/T)$	Schofield, 1967	300-2500°K
16. $H + N_2O \rightarrow HO + N_2$	$(1.2\ ^{+0.7}_{-0.4})[-10]\exp(-7600/T)$	Garvin, 1973b	700-2500°K
17. $H + O_3 \rightarrow HO_2 + O$	$1.0[-12]\exp(-120/T)$		Estimated
18. $HNO_2 + O \rightarrow$ products		Hampson et al., 1972a	No data
19. $HNO_3 + O \rightarrow HO + NO_3$	$\leq 1.5[-14]$	Hampson et al., 1972b	298°K
	$< 1.3[-14]$	Marley & Smith, 1972	300°K

Reactions	Reference Values	References	Remarks
20. $HO + HO \rightarrow H + HO_2$	$(2.0\ ^{+2.0}_{-1.0})[-11]\exp(-20200/T)$	Baulch et al., 1972	290-800°K; Reverse of VIII A 21a
	$(2.0\ ^{+2.0}_{-1.0})[-11]\exp(-20200/T)$	Garvin, 1973a	290-800°K; Reverse of VIII A 21a
21. $HO + NO \rightarrow HNO_2 + h\nu$	$1.0[-10]\exp(-1500/T)$		Estimated
22. $HO + NO \rightarrow H + NO_2$	$(2.8\ ^{+1.6}_{-1.0})[-12]\exp(-15100/T)$	Garvin, 1973b	298-633°K
23. $HO + NO + M \rightarrow HNO_2 + M$	$(4 \pm 2)[-31]$	Anderson & Kaufman, 1972a	M = Ar; 297°K
	$(4.1 \pm 0.6)[-31]$	Morley & Smith, 1972	M = He; 300°K
		Hampson et al., 1973	M = N_2; Preferred values plotted
24. $HO + N_2 \rightarrow H + N_2O$	$(2.5\ ^{+1.5}_{-0.9})[-12]\exp(-39100/T)$	Garvin, 1973b	700-2500°K
25. $HO_2 + H_2 \rightarrow H + H_2O_2$	$(1.2\ ^{+1.2}_{-0.6})[-12]\exp(-9400/T)$	Baulch et al., 1972	300-800°K; Reverse of VIII A 22b
	$1.6[-11]\exp(-12079/T)$	Baulch et al., No.3, 1969	500-1000°K
26. $H_2 + O \rightarrow H + HO$	$(3.0 \pm 0.9)[-14]\text{Texp}(-4480/T)$	Baulch et al., 1972	400-2000°K; Reverse of VIII A 19
	$(4.1 \pm 0.7)[-11]\exp(-4952 \pm 86/T)$	Kondratiev, 1970	340-1700°K
	$2.1[-11]\exp(-4731/T)$	Schofield, 1967	400-2500°K
27. $H_2O + O \rightarrow 2HO$	$(1.1\ ^{+0.6}_{-0.4})[-10]\exp(-9240/T)$	Baulch et al., 1972	300-2000°K; Reverse of VIII A 30
	$1.4[-10]\exp(-9059/T)$	Schofield, 1967	300-900°K
28. $H_2O_2 + NO \rightarrow HO + HNO_2$	$\leq 5[-20]$	Gray et al., 1972	298°K
	$< 1[-24]$	Hampson et al., 1972b	300°K
	$\sim 5[-20]$	Hampson et al., 1973	300°K
29. $N + N \rightarrow N_2 + h\nu$	$(1.0 \pm 0.5)[-17](T/300)^{-0.90 \pm 0.05}$	DNA 1948H, XXIII-4	
30. $N + NO + M \rightarrow N_2O + M$		Schofield, 1973	No evidence of reaction
31a. $N + NO_2 \rightarrow N_2 + O + O$	$(2 \pm 1)[-12]$	DNA 1948H, XXVII-16c	Third channel of VIII A 48
	$2.3[-12]$	Phillips & Schiff, 1965	300°K
31b. $N + NO_2 \rightarrow N_2 + O_2$	$(2 \pm 1)[-12]$	DNA 1948H, XXVII-16d	Fourth channel of VIII A 48
	$1.8[-12]$	Phillips & Schiff, 1965	300°K
32. $N + N_2O \rightarrow NO + N_2$	$1.0[-16]$		Estimated; No data

	Reactions	Reference Values	References	Remarks
33.	$N + O \rightarrow NO + h\nu$	$1.2[-17](T/300)^{-0.35} + 2.1[-34]n_{N_2}(T/300)^{-1.24}$	DNA 1948H, XXIII-2a	
		1.5[-17]	Mandelman et al., 1973	300°K
34.	$N + O + M \rightarrow NO + M$	$(1.8\ ^{+1.1}_{-0.7})[-31]T^{-0.5}$	Garvin, 1973a	M = N_2; 200-400°K
35.	$N + O_3 \rightarrow NO_2 + O$	1.0[-12]exp(-3000/T)		Estimated; VIII A 51 more likely
36.	$NO + NO \rightarrow N_2O + O$	$(2.2\ ^{+2.2}_{-1.1})[-12]\exp(-32100/T)$	Garvin, 1973a	1200-2000°K
37.	$NO + O \rightarrow N + O_2$	(5.3 ± 1.1)[-12]exp(-20200 ± 200/T)	DNA 1948H, XXVII-2	Reverse of VIII A 50
		5.3[-15]Texp(-19678/T)	Schofield, 1967	400-500°K
		$(2.5\ ^{+0.8}_{-0.6})[-15]$Texp(-19500/T)	Garvin, 1973b	1000-3000°K
38.	$NO_2 + NO_2 \rightarrow 2NO + O_2$	3.5[-11]exp(-14273/T)	Schofield, 1967	375-2300°K; Reverse of VIII A 52
39.	$N_2 + O \rightarrow N + NO$	(1.0 ± 0.3)[-10]exp(-37900 ± 300/T)	DNA 1948H, XXVII-1	Reverse of VIII A 47a
		$(1.3\ ^{+1.3}_{-0.7})[-10]\exp(-38000/T)$	Garvin, 1973b	2000-5000°K
40.	$N_2 + O + M \rightarrow N_2O + M$	1[-34 ± 2]exp(-7500/T)	DNA 1948H, XXV-9	Estimated; Very slow at 300°K
		≤ 5[-38]	Schofield, 1973	M = N_2; 300-568°K
		< 5[-38]	Stuhl & Niki, 1971	M = N_2; 300°K
41.	$N_2 + O_2 \rightarrow N_2O + O$	$(1.0^{+1.5}_{-0.6})[-10]\exp(-52200/T)$	Garvin, 1973a	1200-2000°K
42a.	$N_2O + O \rightarrow 2NO$	(1.5 ± 0.5)[-10]exp(-14000 ± 2000/T)	DNA 1948H, XXVII-4	
		4.2[-11]exp(-13450/T)	Baulch et al., No. 4, 1969	
		2.5[-12]exp(-11270/T)	Kondratiev, 1970	900-2300°K
		7.6[-11]exp(-12129/T)	Schofield, 1967	1370-2300°K
		$(1.7\ ^{+1.7}_{-0.9})[-10]\exp(-14100/T)$	Garvin, 1973b	1200-2000°K
42b.	$N_2O + O \rightarrow N_2 + O_2$	(5 ± 2)[-11]exp(-14000 ± 2000/T)	DNA 1948H, XXVII-5	
		4.2[-11]exp(-13450/T)	Baulch et al., No.4, 1969	
		$(1.7\ ^{+2.6}_{-1.0})[-10]\exp(-14100/T)$	Garvin, 1973b	1200-2000°K
43.	$O + O \rightarrow O_2 + h\nu$	2.4[-21]	DNA 1948H, XXIII-1	

Reactions	Reference Values	References	Remarks
C. Reactions of Atmospheric Species not in AIRCHEM			
1a. $O(^1D) + CH_4 \rightarrow CH_3 + HO$	$(3.6\ ^{+0.9}_{-0.7})[-10]$	Garvin, 1973a	298°K
1b. $O(^1D) + CH_4 \rightarrow CH_2O + H_2$	$(4.0\ ^{+1.0}_{-0.8})[-11]$	Garvin, 1973a	298°K
2. $O(^1D) + C_2H_6 \rightarrow$ products	$(4.8\ ^{+1.2}_{-1.0})[-10]$	Garvin, 1973a	298°K
3. $CH_3 + HO \rightarrow$ products	$(6.6 \pm 3.3)[-12]$	Wilson, 1972	1970-2190°K
4. $CH_3 + O_2 \rightarrow CH_2O + HO$	3[-16]	Garvin, 1973a	Estimated
5. $CH_3 + O_2 + M \rightarrow CH_3O_2 + M$	2.6[-31]	Garvin, 1973a	4.3×10^{-13} is high pressure limit
6. $CH_4 \rightarrow CH_3 + H$	2[15]exp(-2000/T)	Benson & O'Neal, 1970	
7a. $CH_4 + H \rightarrow CH_3 + H_2$	$(8.5\ ^{+10.6}_{-0.8})[-12]\exp(-6490 \pm 570/T)$	Kondratiev, 1970	500-2000°K
	$(2.1\ ^{+0.5}_{-0.4})[-10]\exp(-5950 \pm 200/T)$	Walker, 1968	
	6.7[-10]exp(-5843/T)	Schofield, 1967	400-2000°K
7b. $CH_3 + H_2 \rightarrow CH_4 + H$	$(5.5\ ^{+1.0}_{-0.8})[-12]\exp(-6100 \pm 400/T)$	Walker, 1968	
8. $CH_4 + HO \rightarrow CH_3 + H_2O$	$(4.7\ ^{+18.8}_{-3.8})[-11]\exp(-2500/T)$	Wilson, 1972	300-2000°K
	$(4.7\ ^{+18.8}_{-3.8})[-11]\exp(-2500/T)$	Garvin, 1973a	300-2000°K
	$(1.3\ ^{+0.5}_{-0.4})[-10]\exp(-2910 \pm 190/T)$	Kondratiev, 1970	300-1800°K
	1.2[-10]exp(-2974/T)	Schofield, 1967	300-1850°K
9. $CH_4 + O \rightarrow CH_3 + HO$	$(8.3\ ^{+3.7}_{-2.5})[-11]\exp(-4520 \pm 190/T)$	Kondratiev, 1970	
	5.3[-11]exp(-400/T)	Schofield, 1967	295-1000°K
	$(3.5\ ^{+1.0}_{-0.8})[-11]\exp(-4550/T)$	Garvin, 1973a	350-1000°K
10. $CH_4 + O_3 \rightarrow$ products	2.7[-13]exp(-7700/T)	Garvin, 1973a	310-340°K
11. $CHO \rightarrow CO + H$	5[13]exp(-9560/T)	Benson & O'Neal, 1970	
12. $CHO + O_2 \rightarrow CO + HO_2$	1.7[-13]	Garvin, 1973a	Estimated at 300°K
13. $CH_2O + H \rightarrow CHO + H_2$	5.2[-11]exp(-2134/T)	Kondratiev, 1970	300-810°K
	1[-10]exp(-2330/T)	Schofield, 1967	300-850°K

	Reactions	Reference Values	References	Remarks
14.	$CH_2O + HO \rightarrow CHO + H_2O$	8.3[-11 ± 1]	Wilson, 1972	700-1600°K
		9.8[-11]	Kondratiev, 1970	770-1500°K
		$(1.4\ ^{+0.4}_{-0.3})$[-11]	Garvin, 1973a	300°K
15.	$CH_2O + HO_2 \rightarrow CHO + H_2O_2$	7.9[-13 ± 1]exp(-3300/T)	Lloyd, 1970	300-1000°K
		7.9[-13 ± 1]exp(-3300/T)	Garvin, 1973a	300-1000°K
16.	$CH_2O + O \rightarrow CHO + HO$	1.6[-13]	Garvin, 1973a	300°K
17.	$CH_3O \rightarrow CH_2O + H$	1.1[13]exp(-14600/T)	Benson & O'Neal, 1970	
18.	$C_2 + HO \rightarrow CH + CO$	(8.3 ± 3.3)[-12]	Wilson, 1972	2200°K
19.	$C_2H_2 + HO \rightarrow C_2HO + H_2$	(2.0 ± 0.6)[-13]	Wilson, 1972	300-1000°K
20a.	$C_2H_4 + H \rightarrow C_2H_5$	$(1.2\ ^{+0.8}_{-0.5})$[-11]exp(-830 ± 180/T)	Kondratiev, 1970	300-800°K
20b.	$C_2H_5 \rightarrow C_2H_4 + H$	3.2[13]exp(-20480/T)	Benson & O'Neal, 1970	
21.	$C_2H_4 + HO \rightarrow C_2H_3 + H_2O$	$(2.7\ ^{+3.8}_{-1.6})$[-10]exp(-2830 ± 450/T)	Kondratiev, 1970	350-1400°K
		< (5.0 ± 3.2)[-12]	Wilson, 1972	300-2000°K; Products not specified
22.	$C_2H_4 + HO_2 \rightarrow$ products	7.9[-12 ± 1]exp(-2500/T)	Lloyd, 1970	300-1000°K
23.	$C_2H_4 + O \rightarrow C_2H_4O$	$(1.3\ ^{+0.4}_{-0.2})$[-11]exp(-790 ± 60/T)	Kondratiev, 1970	220-670°K
		1.6[-11]exp(-805/T)	Schofield, 1967	223-613°K
		$(5.5\ ^{+1.1}_{-0.9})$[-12]exp(-565/T)	Garvin, 1973a	200-500°K; Products unspecified
24.	$C_2H_5O \rightarrow CH_2O + CH_3$	2.5[13]exp(-8810/T)	Benson & O'Neal, 1970	
25.	$C_2H_6 + H \rightarrow C_2H_5 + H_2$	(1.7 ± 0.3)[-10]exp(-4816 ± 70/T)	Kondratiev, 1970	
		2.2[-10]exp(-5259/T)	Schofield, 1967	300-1400°K
26.	$C_2H_6 + HO \rightarrow C_2H_5 + H_2O$	(1.08 ± 0.08)[-10]exp(-1800 ± 300/T)	Wilson, 1972	300-2000°K
		2.1[-10]exp(-1998/T)	Kondratiev, 1970	300-790°K
27.	$C_2H_6 + HO_2 \rightarrow C_2H_5 + H_2O_2$	1.6[-12 ± 1]exp(-7000 ± 1000/T)	Lloyd, 1970	
28.	$C_2H_6 + O \rightarrow C_2H_5 + HO$	$(4.9\ ^{+3.0}_{-1.9})$[-12]exp(-2300 ± 190/T)	Kondratiev, 1970	300-930°K
		4.3[-11]exp(-2969/T)	Schofield, 1967	300-940°K
		$(4.1\ ^{+1.2}_{-0.9})$[-11]exp(-3200/T)	Garvin, 1973a	300-650°K

	Reactions	Reference Values	References	Remarks
29.	$C_2H_6 \rightarrow 2CH_3$	5.6[16]exp(-45040/T)	Benson & O/Neal, 1970	
30.	$C_2H_3O \rightarrow CH_3 + CO$	2[10]exp(-7550/T)	Benson & O'Neal, 1970	
31.	$C_3H_5O \rightarrow CH_3 + C_2H_2O$	3.2[12]exp(-20100/T)	Benson & O'Neal, 1970	
32a.	$C_3H_6 + H \rightarrow C_3H_7$	5[-11]exp(-1310/T)	Benson & O'Neal, 1970	
32b.	$C_3H_6 + O \rightarrow$ products	$(4.1\ ^{+0.8}_{-0.7})$[-12]exp(-38/T)	Garvin, 1973a	200-500°K
32c.	$C_3H_7 \rightarrow C_3H_6 + H$	2[14]exp(-20790/T)	Benson & O'Neal, 1970	
33.	$C_3H_8 + H \rightarrow C_3H_7 + H_2$	$(1.7\ ^{+0.7}_{-0.5})$[-11]exp(-3130 ± 180/T)	Kondratiev, 1970	350-930°K
		6.8[-11]exp(-3795/T)	Schofield, 1967	300-1200°K
34.	$C_3H_6O + HO_2 \rightarrow C_3H_5O + H_2O_2$	1.6[-12 ± 1]exp(-4000/T)	Lloyd, 1970	300-1000°K
35.	$H + HNO \rightarrow H_2 + NO$	2[-11]exp(-1258/T)	Schofield, 1967	200-2000°K
		(1.0 ± 0.5)[-11]	Hampson et al., 1972a	1600-2000°K
		> 5[-14]	Hampson et al., 1972a	211-703°K
		$(7\ ^{+7}_{-3.5})$[-12]	Hampson et al., 1973	2000°K
36a.	$H + NO + M \rightarrow HNO + M$	$(1.5\ ^{+0.9}_{-0.6})$[-32]exp(300/T)	Garvin, 1973b	M = H_2; 230-700°K
36b.	$HNO + M \rightarrow H + NO + M$	$(5\ ^{+2.9}_{-1.8})$[-8]exp(-24500/T)	Garvin, 1973b	M = H_2; 230-700°K
37.	$HNO + HO \rightarrow H_2O + NO$	(1.5 ± 0.5)[-10]	Hampson et al., 1972a	1600-2200°K
		(1.5 ± 0.5)[-10]	Wilson, 1972	1600-2200°K
		$(7\ ^{+2.8}_{-5.6})$[-11]	Garvin & Hampson, 1972	1600-2100°K
		$(7\ ^{+2.8}_{-5.6})$[-11]	Hampson et al., 1973	1600-2100°K
38.	$HNO + HNO \rightarrow H_2O + N_2O$	$(4\ ^{+4}_{-2})$[-15]	Garvin, 1973b	300°K
39.	$HO + OS \rightarrow H + O_2S$	(1.0 ± 0.5)[-10]	Wilson, 1972	300°K
		$(5.2\ ^{+5.2}_{-2.6})$[-11]	Schofield, 1967	300°K
40.	$HO_2 + O_2S \rightarrow HO + O_3S$	$(3\ ^{+3}_{-1.5})$[-16]	Davis et al., 1972c	300°K

	Reactions	Reference Values	References	Remarks
41a.	$HS + O \rightarrow H + OS$	2[-10]	Schofield, 1967	300°K
41b.	$HS + O \rightarrow HO + S$	$3.8[-13]T^{-0.67}\ \exp(-960/T)$	Schofield, 1967	300°K
42.	$H_2 + NO \rightarrow H + HNO$	$(5.3\ ^{+2.1}_{-1.9})[-18]$	Garvin, 1973b	2000°K
43.	$H_2O + N_2O_5 \rightarrow 2HNO_3$	< 2[-18]	Hampson et al., 1972b	300°K
		< 1[-20]	Hampson et al., 1972b	220°K
		< 1[-20]	Hampson et al, 1973	300°K
44.	$H_2S + O \rightarrow HS + HO$	$(6.3\ ^{+6.3}_{-3.1})[-13]\exp(-920 \pm 180/T)$	Schofield, 1967	200-3500°K
45.	$H_3N + O \rightarrow HO + H_2N$	$(1.8\ ^{+0.5}_{-0.4})[-12]\exp(-2510/T)$	Kondratiev, 1970	350-1000°K
46.	$H_2O + NO \rightarrow HNO + HO$	$(3\ ^{+1.7}_{-1.1})[-18]$	Garvin, 1973b	2000°K
47.	$NO + NO_3 \rightarrow 2NO_2$	7[-12]exp(-850/T)		Estimated
		$\approx(2\ ^{+8.0}_{-1.6})[-11]$	Garvin, 1973b	300°K
48a.	$NO + O_2 + M \rightarrow NO_3 + M$	1[-40]		Estimated; No data
		$(8\ ^{+12}_{-5})[-41]\exp(400/T)$	Garvin, 1973b	M = NO_2; 300-500°K
			Garvin, 1973b	M = N_2; No recommendation
48b.	$NO_3 + M \rightarrow NO + O_2 + M$	1[-13]exp(-2200/T)		Estimated
		$(2.3\ ^{+3.5}_{-1.4})[-13]\exp(-1600/T)$	Garvin, 1973b	M = NO_2; 300-850°K
49a.	$NO_2 + NO_2 \rightarrow N_2O_4$	2.51[-13]	Benson & O/Neal, 1970	
49b.	$N_2O_4 \rightarrow 2NO_2$	1[16]exp(-6590/T)	Benson & O/Neal, 1970	
49c.	$N_2O_4 + M \rightarrow 2NO_2 + M$	$(3.3 \pm 1.3)[-7]\exp(-5586/T)$	Schofield, 1973	M = N_2; 250-350°K
		3.31[-7]exp(-5500/T)	Bahn, 1965	
50a.	$NO_2 + NO_3 \rightarrow NO + NO_2 + O_2$	$(3.2 \pm 0.7)[-13]\exp(-1990 \pm 110/T)$	Kondratiev, 1970	500-1100°K
		$(2.3\ ^{+3.5}_{-1.4})[-13]\exp(-1000/T)$	Garvin, 1973a	300-850°K
50b.	$NO_2 + NO_3 \rightarrow N_2O_5$	6.3[-13]	Benson & O'Neal, 1970	
		$(3.8\ ^{+5.7}_{-2.3})[-12]$	Garvin, 1973b	Two-body limit
		(7.1 to 190)[-14]	Garvin, 1973a	Over altitude range 15-45 km

	Reactions	Reference Values	References	Remarks
50c.	$NO_2 + NO_3 + M \rightarrow N_2O_5 + M$	$(2.8\ ^{+2.8}_{-1.4})[-30]$	Garvin, 1973b	$M = N_2O_5 + NO$; 300°K
50d.	$N_2O_5 \rightarrow NO_2 + NO_3$	6[14]exp(-10570/T)	Benson & O'Neal, 1970	
		$(5.7\ ^{+8.6}_{-3.4})$[14]exp(-10600/T)	Garvin, 1973b	273-300°K; High pressure limit
50e.	$N_2O_5 + M \rightarrow NO_2 + NO_3 + M$	8.32[-8]exp(-8300 ± 400/T)	Bahn, 1965	
		$(2.2\ ^{+2.2}_{-1.1})$[-5]exp(-9700/T)	Garvin, 1973b	$M = N_2O_5 + NO$; 300-340°K
51.	$NO_2 + O + M \rightarrow NO_3 + M$	(5.8 ± 2.3)[-32]	Hampson et al., 1972a	$M = N_2$; 298°K
		1.6[-11]	Hampson et al., 1972a	Effective two-body value at high pressures
		(1.0 ± 0.5)[-31]	Hampson et al., 1973	$M = N_2$; 298°K
52.	$NO_2 + O_3 \rightarrow NO_3 + O_2$	9.8[-12]exp(-3500 ± 300/T)	DNA 1948H, XXVII-20a	
		9.8[-12]exp(-3500/T)	Johnston & Yost, 1949	
		(6.1 ± 1.8)[-17]	Hampson et al., 1972a	294°K
		$(5.0\ ^{+2.9}_{-1.8})$[-17]	Hampson et al., 1973	298°K
		$(6.3\ ^{+3.7}_{-2.3})$[-12]exp(-3500/T)	Garvin, 1973a	
53.	$NO_3 + NO_3 \rightarrow 2NO_2 + O_2$	4[-12]exp(-3850/T)		Estimated; No data
		$(5\ ^{+11}_{-3.4})$[-12]exp(-3000/T)	Garvin, 1973b	293-309K
54.	$NO_3 + O \rightarrow NO_2 + O_2$	1[-12]exp(-1500/T)		Estimated; No data
55.	$NO_3 + O_2 \rightarrow NO_2 + O_3$	$(7\ ^{+11}_{-4})$[-34]	Garvin, 1973b	300°K
56.	$N_2O_5 + O \rightarrow 2NO_2 + O_2$	1[-13]		Estimated; No data
57.	$O + O + O \rightarrow O(^1S) + O_2$	1.5[-34 ± 1]	DNA 1948H, XXV-1	
58.	$O + O_3S \rightarrow O_2 + O_2S$	4.6[-10]exp(-6000/T)	Schofield, 1967	
59.	$O_2 + OS \rightarrow O + O_2S$	$(3.0\ ^{+3.0}_{-1.5})$[-13]exp(-2818/T)	Schofield, 1973	400-2500°K
60.	$O_3 + OS \rightarrow O_2 + O_2S$	2.5[-12]exp(-1050/T)	Schofield, 1967	220-300°K

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TABLE VIII

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