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Compilation of Reaction Rate Data for Nonequilibrium Performance and Reentry Calculation Programs

JANUARY 1967

Prepared by THERMOCHEMISTRY RESEARCH DEPARTMENT
Aerodynamics and Propulsion Research Laboratory
Laboratories Division
Laboratory Operations
AEROSPACE CORPORATION

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Prepared for BALLISTIC SYSTEMS AND SPACE SYSTEMS DIVISIONS
AIR FORCE SYSTEMS COMMAND
LOS ANGELES AIR FORCE STATION
Los Angeles, California

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Prepared by

Thermochemistry Research Department
Aerodynamics and Propulsion Research Laboratory

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FOREWORD

This report is published by the Aerospace Corporation, El Segundo, California, under Air Force Contract No. AF 04(695)-1001. The report was authored by R. Tunder, S. Mayer, E. Cook, and L. Schieler of the Thermochemistry Research Department.

This report, which documents research carried out from June 1966 to September 1966, was submitted on 15 March 1967 to Captain John T. Allton, USAF, for review and approval.

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Publication of this report does not constitute Air Force approval of the report's findings or conclusions. It is published only for the exchange and stimulation of ideas.

John T. Allton, Captain, USAF
Space Systems Division
Air Force Systems Command

ABSTRACT

A compilation of gas-phase rate data for use in nonequilibrium gas composition and propellant performance calculation programs is presented. Reactions are listed with the preexponential factor, temperature exponent, and activation energy for the Arrhenius form of the rate equation. Only undirectional rate data are supplied since reverse rates may be generated from thermochemical data. Explanatory notes on the estimation of the rate data are included with the references.

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INTRODUCTION

This report is a compilation of gas-phase rate data for use in nonequilibrium gas composition and propellant performance calculation programs. The data are given for the Arrhenius rate equation, $k = AT^n \exp(-E/RT)$ where A is the frequency factor, T is the absolute temperature, n determines the preexponential temperature dependence, E is the activation energy, and R is the gas constant. Only forward rate data are presented; rates for the reverse reactions can be calculated by means of the equilibrium constant.

The tabulation of the gas-phase rate data is as follows:

Reactions of aluminum species (Table 1)

1. Al
2. AlCl, $AlCl_2$, $AlCl_3$
3. AlF, AlF_2, AlF_3
4. AlH
5. AlO
6. Al_2O
7. AlOCl
8. AlOF
9. AlOH
10. AlO_2H, etc.

Reactions of beryllium species (Table 2)

1. Be
2. BeCl
3. BeF
4. BeH
5. BeO

Reactions of boron species (Table 3)
Reactions of carbon species (Tables 4 and 5)
Reactions of lithium species (Table 6)
Reactions of nitrogen species (Table 7)
Reactions of potassium species (Table 8)
Reactions of sodium species (Table 9)
Reactions of chlorine (Table 10) and fluorine species (Table 11)
Reactions of oxygen (Table 12) and hydrogen species (Table 13)

The order of the tables (Table 1 through 13) is alphabetical with respect to names of the elements. Thus, aluminum reactions come first, even if they involve beryllium, boron, carbon, etc. Within each table, reactions of species containing the major element are listed alphabetically with species containing the smallest number of atoms listed first. Among the reactions involving two-atom and three-atom species, for example, the listing is alphabetical with respect to the elements. This species is always listed first in the equation, and the arrangement is based entirely on reactants, not products. Catalyzed reactions are listed before uncatalyzed reactions, and reactions with specific catalysts are listed alphabetically with respect to catalysts. The arrangement of reactions of a given species is alphabetical with respect to the other reactant (or reactants). All reactions with single-atom reactants come first, two-atom reactants are next, etc.

There are a number of exceptions to these organizational rules. Alphabetical order is as noted except for chlorine, fluorine, oxygen, and hydrogen; these are listed in that order, at the end of the table after sodium. This exception does not occur within the various tables. Halogen and oxide species in a table are often listed together instead of according to the numerical rule. AlCl, $AlCl_2$, and $AlCl_3$ are listed successively before AlF, AlF_2, and AlF_3, which are all listed before

AlH. O and O_2 reactions are listed successively before OH. All charges are ignored in arranging reactions except when an isolated electron is a reactant; these reactions are then arranged alphabetically as single-atom reactants.

The references cited in the tables show the source of the data; where no kinetic data are available, the constants were estimated by recommended procedures as indicated in the references.

Many of the reaction rates are based on Ref. (2). For these cases, rate constants of nonionic reactions were estimated on the basis of the report cited in Ref. (1). A, n, and E were chosen to correspond to those of similar reactions in this report. For exothermic bimolecular reactions, $A = 5 \times 10^{11}$ cc/mole-sec, $n = 0.5$, $E = 5.5\%$ of the energy of the bond being broken for triatomic transition states (Hirschfelder rule). For transition states of more than three atoms, $A = 1 \times 10^{11}$ cc/mole-sec. Typically, for exothermic trimolecular reactions, $A = 3 \times 10^{16}$ $cc^2/moles^2$ sec, $n = -0.5$, and $E = 0$.

Reactions based on Ref. (2), involving ions or electrons, use the report in Ref. (21) as their basis. For charge transfer reactions, $A = 4 \times 10^{11}$, $n = 0.5$, and $E = 0$. For reactions of the type $X^+ + e + M$, where M is, as in the tables, any third body that acts as a catalyst, $A = 5 \times 10^{23}$, $n = -1.5$, and $E = 0$. For the type $X^+ + Y^- + M = XY + M$, $A = 4 \times 10^{17}$, $n = -0.5$, and $E = 0$. For $X + e + M = X^- + M$, $A = 1 \times 10^{20}$, $n = -1.0$, and $E = 0$. For $x + Y^- + M = XY^- + M$, $A = 4 \times 10^{17}$, $n = -0.5$, and $E = 0$. For exothermic reactions of the type $X^- + Y = XY + e$, $A = 5 \times 10^{11}$, $n = 0.5$, and $E = 0$.

Although many of the tabulated reactions contain M, a generalized third-body catalyst, specific third bodies are included wherever the information is available. For example, the hydrogen-fluorine reactions (Refs. 3 and 19) have H_2, H, and HF as specific third bodies, each with

slightly different k_f values. Atomic fluorine is present in such systems at a much lower concentration and has a negligible effect as a third body; therefore third-body reactions with F as a catalyst are not listed. When a generalized third-body reaction rate was not available, but desirable, and several specific third body rates were available, A for the generalized reaction rate has been obtained from a weighted geometric mean of the A's for the specific reaction rates. The weighting is based on the concentration of each specific third body. If the concentrations of the specific third bodies are y_i, the weighted geometric mean is

$$A_m = (\prod_i A_i^{y_i})^{1/\sum_i y_i}.$$

All the rates associated with Ref. (36) are hydrogen transfer reactions (AH + B = A + HB). The collision equation used to estimate the rates of these reactions is a modification of the equation referred to in Ref. (36). In units of cc/mole-sec, $k_f = 2.74 \times 10^{12}\ P\ \sigma_{AB}^{2}\ \mu^{\frac{1}{2}}\ T^{\frac{1}{2}}\ r_s\ (g_{BH}\ g_A/g_{AH}\ g_B)^{\frac{1}{2}}$. Here, E = 0, n = $\frac{1}{2}$, and the equation really determines A. In the equation P = 0.1 (steric factor for polyatomic reactants), g is the electronic multiplicity, σ_{AB} is the internuclear distance (in angstroms) between colliding species, μ is the reduced mass, and r_s is the number of equivalent hydrogens on AH.

Table 1. Reactions Involving Aluminum Species

Reaction	A, cc/mole-sec	n	E, kcal/mole	Reference
$Al + AlCl_2 = 2\ AlCl$	1×10^{11}	0.5	5	2
$Al + AlClF = AlCl + AlF$	1×10^{11}	0.5	6	2
$Al + AlOCl = Al_2O + Cl$	1×10^{11}	0.5	8	2
$Al + AlCl_3 = AlCl + AlCl_2$	1×10^{11}	0.5	5	2
$Al + AlF_2 = 2AlF$	1×10^{11}	0.5	6	2
$Al + AlOF = AlF + AlO$	1×10^{11}	0.5	9	2
$Al + AlClF_2 = AlF + AlClF$	1×10^{11}	0.5	7	2
$Al + AlClF_2 = AlCl + AlF_2$	1×10^{11}	0.5	6	2
$Al + AlCl_2F = AlF + AlCl_2$	1×10^{11}	0.5	7	2
$Al + AlCl_2F = AlCl + AlClF$	1×10^{11}	0.5	6	2
$Al + AlF_3 = AlF + AlF_2$	1×10^{11}	0.5	7	2
$Al + AlOH = Al_2O + H$	1×10^{11}	0.5	4	2
$Al + AlO + M = Al_2O + M$	3×10^{16}	-0.5	0	2
$Al + Al_2O^+ = Al^+ + Al_2O$	5×10^{11}	0.5	0	2
$Al^+ + AlO + M = Al_2O^+ + M$	3×10^{16}	-0.5	0	2
$Al + AlO_2H = AlOH + AlO$	5×10^{10}	0.5	6	2
$Al + AlO_2H = OH + Al_2O$	1×10^{11}	0.5	5	2
$Al^+ + AlO_2H = OH + Al_2O^+$	1×10^{11}	0.5	5	2
$Al + Al_2O_2 = AlO + Al_2O$	5×10^{10}	0.5	6	2
$Al + Be^+ = Al^+ + Be$	4×10^{11}	0.5	0	2

Table 1. Reactions Involving Aluminum Species (Continued)

Reaction	A, cc/mole-sec	n	E, kcal/mole	Reference
$Al + BeCl = Be + AlCl$	5×10^{11}	0.5	6	2
$Al + BeF = AlF + Be$	5×10^{11}	0.5	8	2
$Al + BeH = AlH + Be$	8.5×10^{11}	0.7	4	22
$Al + BeO = AlO + Be$	5×10^{11}	0.5	6	2
$Al + BeClF = BeCl + AlF$	1×10^{11}	0.5	7	2
$Al^{+} + CHO = Al + CHO^{+}$	5×10^{11}	0.5	0	2
$Al + CHO = AlH + CO$	1×10^{11}	0.5	2	2
$Al + Cl^{-} = AlCl + e$	5×10^{11}	0.5	0	2
$Al + Cl_2 = AlCl + Cl$	5×10^{11}	0.5	3	2
$Al + Cl + M = AlCl + M$	3×10^{16}	-0.5	0	2
$Al^{+} + Cl^{-} + M = AlCl + M$	4×10^{17}	-0.5	0	2
$Al + ClF = AlF + Cl$	5×10^{11}	0.5	3	2
$Al + ClF = AlCl + F$	5×10^{11}	0.5	3	2
$Al + ClH = AlCl + H$	5×10^{11}	0.5	6	2
$Al^{+} + ClLi = AlCl + Li^{+}$	1×10^{11}	0.5	6	2
$Al + ClLi = AlCl + Li$	5×10^{11}	0.5	6	2
$Al + ClK = AlCl + K$	5×10^{11}	0.5	7	2
$Al^{+} + ClK = AlCl + K^{+}$	1×10^{11}	0.5	7	2
$Al + ClNa = AlCl + Na$	5×10^{11}	0.5	5	2
$Al^{+} + ClNa = AlCl + Na^{+}$	5×10^{11}	0.5	5	2

Table 1. Reactions Involving Aluminum Species (Continued)

Reaction	A, cc/ mole-sec	n	E, kcal/mole	Reference
$Al^+ + e + M = Al + M$	5×10^{23}	-1.5	0	2
$Al + F + M = AlF + M$	3×10^{16}	-0.5	0	2
$Al^+ + F^- + M = AlF + M$	4×10^{17}	-0.5	0	2
$Al + F_2 = AlF + F$	5×10^{11}	0.5	2	2
$Al + FH = AlF + H$	5×10^{11}	0.5	7	2
$Al^+ + LiH = AlH + Li^+$	1×10^{11}	0.5	3	2
$Al + FLi = AlF + Li$	5×10^{11}	0.5	7	2
$Al^+ + FLi = AlF + Li^+$	1×10^{11}	0.5	7	2
$Al + LiO = AlO + Li$	5×10^{11}	0.5	5	2
$Al^+ + LiO = AlO + Li^+$	1×10^{11}	0.5	5	2
$Al + FK = AlF + K$	5×10^{11}	0.5	7	2
$Al^+ + FK = AlF + K^+$	1×10^{11}	0.5	7	2
$Al + FNa = AlF + Na$	5×10^{11}	0.5	6	2
$Al^+ + FNa = AlF + Na^+$	1×10^{11}	0.5	6	2
$Al^+ + H^- + M = AlH + M$	4×10^{17}	-0.5	0	2
$Al + H + M = AlH + M$	3×10^{16}	-0.5	0	2
$Al + H^- = e + AlH$	5×10^{11}	0.5	0	2
$Al + HO = AlO + H$	5×10^{11}	0.5	6	2
$Al + LiH = Li + AlH$	3.0×10^{12}	0.7	9	22
$Al + OH + M = AlOH + M$	3×10^{12}	-0.5	0	2

Table 1. Reactions Involving Aluminum Species (Continued)

Reaction	A, cc/ mole-sec	n	E, kcal/mole	Reference
$Al + H_2O = AlOH + H$	1×10^{11}	0.5	6	2
$Al + H_3O^+ = Al^+ + H + H_2O$	1×10^{10}	0.5	6	2
$Al^+ + NaH = AlH + Na^+$	5×10^{11}	0.5	7	2
$Al + NaH = Na + AlH$	9.7×10^{11}	0.7	6	22
$Al^+ + Li = Al + Li^+$	4×10^{11}	0.5	0	2
$Al + NO^+ = Al^+ + NO$	5×10^{11}	0.5	0	2
$Al + O^- = AlO + e$	5×10^{11}	0.5	0	2
$Al + O + M = AlO + M$	3×10^{16}	-0.5	0	2
$Al^+ + O^- + M = AlO + M$	4×10^{17}	-0.5	0	2
$Al + O_2 = AlO + O$	5×10^{11}	0.5	6	2
$Al + O_2^- = AlO + O^-$	5×10^{11}	0.5	6	2
$Al^+ + O_2^- = AlO + O$	5×10^{11}	0.5	6	2
$Al^+ + K = Al + K^+$	4×10^{11}	0.5	0	2
$Al^+ + Na = Al + Na^+$	4×10^{11}	0.5	0	2
$Al + NaO = AlO + Na$	5×10^{11}	0.5	4	2
$Al^+ + NaO = AlO + Na^+$	5×10^{11}	0.5	6	2
$AlCl + AlCl_3 = 2AlCl_2$	1×10^{11}	0.5	5	2
$AlCl + AlCl_2F = AlCl_2 + AlClF$	1×10^{11}	0.5	6	2
$AlCl + AlClF_2 = 2AlClF$	1×10^{11}	0.5	7	2
$AlCl_2 + AlF_2 = AlCl + AlClF_2$	1×10^{11}	0.5	5	2

Table 1. Reactions Involving Aluminum Species (Continued)

Reaction	A, cc/ mole-sec	n	E, kcal/mole	Reference
$AlCl_2 + AlF_2 = AlF + AlCl_2F$	1×10^{11}	0.5	6	2
$AlCl_3 + AlF = AlClF + AlCl_2$	1×10^{11}	0.5	5	2
$AlCl + AlO = AlOCl + Al$	1×10^{11}	0.5	6	2
$AlCl + AlO = Al_2O + Cl$	1×10^{11}	0.5	6	2
$AlCl + AlO_2H = AlOCl + AlOH$	1×10^{11}	0.5	6	2
$AlCl_2 + AlO = AlCl + AlClO$	1×10^{11}	0.5	5	2
$AlCl + BeCl = AlCl_2 + Be$	1×10^{11}	0.5	6	2
$AlCl + BeCl = Al + BeCl_2$	1×10^{11}	0.5	6	2
$AlCl_2 + BeCl = AlCl + BeCl_2$	1×10^{11}	0.5	5	2
$AlCl_2 + BeCl = AlCl_3 + Be$	1×10^{11}	0.5	6	2
$AlCl_3 + BeCl = AlCl_2 + BeCl_2$	1×10^{11}	0.5	5	2
$AlCl + BeF = BeClF + Al$	1×10^{11}	0.5	6	2
$AlCl + BeF = AlClF + Be$	1×10^{11}	0.5	8	2
$AlCl_2 + BeF = AlCl_2F + Be$	1×10^{11}	0.5	8	2
$AlCl_2 + BeF = BeFCl + AlCl$	1×10^{11}	0.5	5	2
$AlCl + CO_2 = CO + AlClO$	5×10^{10}	0.5	7	2
$AlCl + F_2 = AlClF + F$	1×10^{11}	0.5	2	2
$AlCl_2 + F = AlFCl_2$	1×10^{11}	0.5	0	2
$AlCl + ClF = AlClF + Cl$	1×10^{11}	0.5	3	2
$AlCl_2 + KF = AlCl_2F + K$	1×10^{11}	0.5	7	2

Table 1. Reactions Involving Aluminum Species (Continued)

Reaction	A, cc/ mole-sec	n	E, kcal/mole	Reference
$AlCl + NaF = AlClF + Na$	1×10^{11}	0.5	7	2
$AlCl_2 + NaF = AlCl_2F + Na$	1×10^{11}	0.5	6	2
$AlCl + Cl + M = AlCl_2 + M$	3×10^{16}	-0.5	0	2
$AlCl + Cl^- = AlCl_2 + e$	1×10^{11}	0.5	0	2
$AlCl + Cl_2 = AlCl_2 + Cl$	1×10^{11}	0.5	3	2
$AlCl + ClF = AlCl_2 + F$	1×10^{11}	0.5	3	2
$AlCl_2 + Cl = AlCl_3$	1×10^{11}	0.5	0	2
$AlCl_2 + Cl^- = AlCl_3 + e$	1×10^{11}	0.5	0	2
$AlCl + F + M = AlFCl + M$	3×10^{16}	-0.5	0	2
$AlCl + KF = AlClF + K$	1×10^{11}	0.5	7	2
$AlCl_2 + H = AlCl + HCl$	1×10^{11}	0.5	5	2
$AlCl_3 + H = HCl + AlCl_2$	1×10^{11}	0.5	5	2
$AlCl + LiO = AlOCl + Li$	1×10^{11}	0.5	6	2
$AlCl_2 + Li = AlCl + LiCl$	1×10^{11}	0.5	5	2
$AlCl_3 + Li = LiCl + AlCl_2$	1×10^{11}	0.5	5	2
$AlCl + M + O = AlOCl + M$	3×10^{16}	-0.5	0	2
$AlCl + O^- = AlOCl + e$	1×10^{11}	0.5	0	2
$AlCl + O^- = AlO + Cl^-$	5×10^{11}	0.5	3	2
$AlCl + O_2 = AlOCl + O$	1×10^{11}	0.5	6	2
$AlCl + O_2^- = AlOCl + O^-$	1×10^{11}	0.5	5	2

Table 1. Reactions Involving Aluminum Species (Continued)

Reaction	A, cc/mole-sec	n	E, kcal/mole	Reference
$AlCl_2 + O = AlOCl + Cl$	1×10^{11}	0.5	5	2
$AlCl_2 + O^- = AlOCl + Cl^-$	1×10^{10}	0.5	5	2
$AlCl_2 + K = AlCl + KCl$	5×10^{11}	0.5	5	2
$AlCl_3 + K = KCl + AlCl_2$	1×10^{11}	0.5	5	2
$AlCl_2 + Na = AlCl + NaCl$	1×10^{11}	0.5	5	2
$AlCl + NaO = AlOCl + Na$	1×10^{11}	0.5	4	2
$AlCl_3 + Na = NaCl + AlCl_2$	5×10^{10}	0.5	5	2
$AlClF + AlF_2 = AlF + AlClF_2$	1×10^{11}	0.5	6	2
$AlClF + AlF_2 = AlCl + AlF_3$	1×10^{11}	0.5	7	2
$AlClF + AlO = AlF + AlOCl$	1×10^{11}	0.5	6	2
$AlClF + AlO = AlCl + AlOF$	1×10^{11}	0.5	7	2
$AlClF + BeCl = AlFCl_2 + Be$	1×10^{11}	0.5	6	2
$AlClF + BeCl = AlCl + BeClF$	1×10^{11}	0.5	7	2
$AlFCl + BeCl = BeCl_2 + AlF$	1×10^{11}	0.5	6	2
$AlFCl + BeCl = AlFCl_2 + Be$	1×10^{11}	0.5	6	2
$AlClF + BeF = AlClF_2 + Be$	1×10^{11}	0.5	8	2
$AlClF + BeF = AlCl + BeF_2$	1×10^{11}	0.5	7	2
$AlClF + BeF = BeFCl + AlF$	1×10^{11}	0.5	6	2
$AlClF + Cl = AlCl_2F$	1×10^{11}	0.5	0	2
$AlClF + F = AlClF_2$	1×10^{11}	0.5	0	2

Table 1. Reactions Involving Aluminum Species (Continued)

Reaction	A, cc/ mole-sec	n	E, kcal/mole	Reference
$AlClF + KF = AlClF_2 + K$	1×10^{11}	0.5	7	2
$AlClF + NaF = AlClF_2 + Na$	1×10^{11}	0.5	6	2
$AlClF + H = AlCl + HF$	1×10^{11}	0.5	7	2
$AlClF + H = AlF + HCl$	1×10^{11}	0.5	6	2
$AlClF + Li = AlCl + LiF$	1×10^{11}	0.5	7	2
$AlClF + Li = AlF + LiCl$	1×10^{11}	0.5	6	2
$AlClF + O^- = AlOF + Cl^-$	5×10^{10}	0.5	6	2
$AlClF + O^- = AlOCl + F^-$	5×10^{10}	0.5	7	2
$AlClF + O = AlOF + Cl$	1×10^{11}	0.5	6	2
$AlClF + Na = AlF + NaCl$	1×10^{11}	0.5	6	2
$AlCl_2F + AlF = 2AlClF$	1×10^{11}	0.5	6	2
$AlCl_2F + BeCl = BeClF + AlCl_2$	1×10^{11}	0.5	8	2
$AlCl_2F + BeCl = BeCl_2 + AlFCl$	1×10^{11}	0.5	6	2
$AlClF_2 + BeF = BeF_2 + AlClF$	1×10^{11}	0.5	8	2
$AlClF_2 + BeF = BeFCl + AlF_2$	1×10^{11}	0.5	6	2
$AlCl_2F + H = AlClF + HCl$	1×10^{11}	0.5	6	2
$AlCl_2F + H = AlCl_2 + HF$	1×10^{11}	0.5	7	2
$AlCl_2F + Li = LiF + AlCl_2$	1×10^{11}	0.5	7	2
$AlCl_2F + Li = LiCl + AlClF$	1×10^{11}	0.5	6	2
$AlCl_2F + K = KCl + AlClF$	1×10^{11}	0.5	6	2

Table 1. Reactions Involving Aluminum Species (Continued)

Reaction	A, cc/ mole-sec	n	E, kcal/mole	Reference
$AlCl_2F + Na = AlClF + NaCl$	1×10^{11}	0.5	6	2
$AlClF_2 + BeCl = BeCl_2 + AlF_2$	1×10^{11}	0.5	6	2
$AlClF_2 + BeCl = BeFCl + AlFCl$	1×10^{11}	0.5	8	2
$AlClF_2 + BeF = AlF_2 + BeClF$	1×10^{11}	0.5	6	2
$AlClF_2 + BeF = AlClF + BeF_2$	1×10^{11}	0.5	8	2
$AlClF_2 + H = AlF_2 + HCl$	1×10^{11}	0.5	6	2
$AlClF_2 + H = AlClF + HF$	1×10^{11}	0.5	7	2
$AlClF_2 + Li = AlF_2 + LiCl$	1×10^{11}	0.5	6	2
$AlClF_2 + Li = AlClF + LiF$	1×10^{11}	0.5	7	2
$AlF + AlO_2H = AlOF + AlOH$	1×10^{11}	0.5	6	2
$AlF + Al_2O_2 = AlOF + Al_2O$	1×10^{11}	0.5	6	2
$2AlF_2 = AlF + AlF_3$	1×10^{11}	0.5	6	2
$AlF_2 + AlO = AlF + AlOF$	1×10^{11}	0.5	6	2
$AlF + BeCl = AlClF + Be$	1×10^{11}	0.5	6	2
$AlF_2 + BeCl = AlClF_2 + Be$	1×10^{11}	0.5	6	2
$AlF_2 + BeCl = BeClF + AlF$	1×10^{11}	0.5	6	2
$AlF + BeO = AlOF + Be$	1×10^{11}	0.5	9	2
$AlF + BeF = Be + AlF_2$	1×10^{11}	0.5	8	2
$AlF + BeF = BeF_2 + Al$	1×10^{11}	0.5	9	2
$AlF_2 + BeF = BeF_2 + AlF$	1×10^{11}	0.5	6	2

Table 1. Reactions Involving Aluminum Species (Continued)

Reactions	A, cc/ mole-sec	n	E, kcal/mole	Reference
$AlF_2 + BeF = Be + AlF_3$	1×10^{11}	0.5	8	2
$AlF_3 + BeF = BeF_2 + AlF_2$	1×10^{11}	0.5	8	2
$AlF + Cl + M = AlClF + M$	3×10^{16}	-0.5	0	2
$AlF_2 + Cl = AlClF_2$	1×10^{11}	0.5	0	2
$AlF_2 + KCl = AlClF_2 + K$	1×10^{11}	0.5	6	2
$AlF + ClF = AlClF + F$	1×10^{11}	0.5	3	2
$AlF_2 + NaCl = AlClF_2 + Na$	1×10^{11}	0.5	5	2
$AlF_2 + KF = AlF_3 + K$	1×10^{11}	0.5	7	2
$AlF + ClF = AlF_2 + Cl$	1×10^{11}	0.5	3	2
$AlF + F + M = AlF_2 + M$	3×10^{16}	-0.5	0	2
$AlF + F_2 = AlF_2 + F$	1×10^{11}	0.5	2	2
$AlF_2 + F = AlF_3$	1×10^{11}	0.5	0	2
$AlF_2 + HF = H + AlF_3$	1×10^{11}	0.5	7	2
$AlF_2 + LiF = Li + AlF_3$	1×10^{11}	0.5	7	2
$AlF + NaF = AlF_2 + Na$	1×10^{11}	0.5	6	2
$AlF_2 + NaF = Na + AlF_3$	1×10^{11}	0.5	6	2
$AlF_2 + H = AlF + HF$	1×10^{11}	0.5	6	2
$AlF + OH = AlOF + H$	1×10^{11}	0.5	6	2
$AlF_2 + Li = AlF + FLi$	1×10^{11}	0.5	9	2
$AlF + LiO = AlOF + Li$	1×10^{11}	0.5	5	2

Table 1. Reactions Involving Aluminum Species (Continued)

Reaction	A, cc/ mole-sec	n	E, kcal/mole	Reference
$AlF + O + M = AlOF + M$	3×10^{16}	-0.5	0	2
$AlF_2 + O = AlOF + F$	1×10^{11}	0.5	6	2
$AlF + O_2^- = AlOF + O^-$	1×10^{11}	0.5	5	2
$AlF_2 + K = AlF + FK$	5×10^{11}	0.5	6	2
$AlF + NaO = AlOF + Na$	1×10^{11}	0.5	4	2
$AlH + AlO = AlOH + Al$	1×10^{11}	0.5	4	2
$AlH + AlO = Al_2O + H$	1×10^{11}	0.5	4	2
$AlH + BeH = BeH_2 + Al$	1×10^{11}	0.5	4	2
$AlH + BeO = BeOH + Al$	1×10^{11}	0.5	4	2
$AlH + BeO = AlOH + Be$	1×10^{11}	0.5	6	2
$AlH + B = Al + BH$	2.4×10^{12}	0.7	8	22
$AlH + C = Al + CH$	1.4×10^{12}	0.7	13	22
$AlH + CN = Al + HCN$	1×10^{11}	0.5	4	2
$AlH + Cl = AlCl + H$	5×10^{11}	0.5	4	2
$AlH + Cl = Al + HCl$	1.4×10^{11}	0.7	8	22
$AlH + F = Al + HF$	1.5×10^{11}	0.7	6	22
$AlH + H = Al + H_2$	9.1×10^{11}	0.7	4	22
$AlH + NH = Al + NH_2$	1×10^{11}	0.5	4	2
$AlH + LiO = Al + LiOH$	1×10^{11}	0.5	4	2
$AlH + N = Al + HN$	5.6×10^{11}	0.7	6	22

Table 1. Reactions Involving Aluminum Species (Continued)

Reaction	A, cc/ mole-sec	n	E, kcal/mole	Reference
$AlH + O = Al + HO$	2.8×10^{11}	0.7	8	22
$AlH + O^- = Al + OH^-$	5×10^{11}	0.5	3	2
$AlH + O = AlO + H$	5×10^{11}	0.5	4	2
$AlH + OH = AlOH + H$	5×10^{10}	0.5	6	2
$AlH + OH = Al + H_2O$	1×10^{11}	0.5	4	2
$AlH + NaO = Al + NaOH$	1×10^{11}	0.5	4	2
$2AlO = Al_2O_2$	1×10^{11}	0.5	0	2
$2AlO = Al_2O + O$	1×10^{11}	0.5	6	2
$AlO + AlOH = Al_2O + OH$	1×10^{11}	0.5	4	2
$AlO + AlOH = Al_2O_2 + H$	1×10^{11}	0.5	5	2
$AlO + Al_2O^+ = Al^+ + Al_2O_2$	1×10^{10}	0.5	6	2
$AlO + BeCl = AlOCl + Be$	1×10^{11}	0.5	6	2
$AlO + BeH = AlOH + Be$	1×10^{11}	0.5	3	2
$AlO + BeOH = BeO + AlOH$	1.3×10^{11}	0.5	0	36
$AlO + CH_2 = CH + AlOH$	4.3×10^{11}	0.5	0	36
$AlO + CH_3 = CH_2 + AlOH$	2.5×10^{11}	0.7	6	22
$AlO + CH_4 = CH_3 + AlOH$	2.2×10^{12}	0.7	10	22
$AlO + HCO = CO + AlOH$	6×10^{10}	0.7	4	22
$AlO + H_2CO = HCO + AlOH$	2.7×10^{11}	0.7	10	22
$AlO + HCN = CN + AlOH$	5.1×10^{11}	0.7	21	22

Table 1. Reactions Involving Aluminum Species (Continued)

Reaction	A, cc/ mole-sec	n	E, kcal/mole	Reference
$AlO + CO = Al + CO_2$	1×10^{11}	0.5	6	2
$AlO + M + Cl = AlClO + M$	3×10^{16}	-0.5	0	2
$AlO + Cl = AlCl + O$	5×10^{11}	0.5	6	2
$AlO + Cl^- = AlOCl + e$	1×10^{11}	0.5	0	2
$AlO + Cl_2 = AlOCl + Cl$	1×10^{11}	0.5	3	2
$AlO + ClF = AlOF + Cl$	1×10^{11}	0.5	3	2
$AlO + ClF = AlOCl + F$	1×10^{11}	0.5	3	2
$AlO + HCl = AlOCl + H$	1×10^{11}	0.5	6	2
$AlO + NaCl = AlOCl + Na$	1×10^{11}	0.5	6	2
$AlO + F + M = AlOF + M$	3×10^{16}	-0.5	0	2
$AlO + F = AlF + O$	5×10^{11}	0.5	6	2
$AlO + F_2 = AlOF + F$	1×10^{11}	0.5	2	2
$AlO + HF = AlOF + H$	1×10^{11}	0.5	7	2
$AlO + LiF = AlOF + Li$	1×10^{11}	0.5	7	2
$AlO + KF = AlOF + K$	1×10^{11}	0.5	7	2
$AlO + NaF = AlOF + Na$	1×10^{11}	0.5	6	2
$AlO + H^- = Al + OH^-$	5×10^{11}	0.5	6	2
$AlO + H + M = AlHO + M$	3×10^{16}	-0.5	0	2
$AlO + LiH = AlOH + Li$	1×10^{11}	0.5	3	2
$AlO + OH = HAlO_2$	1×10^{11}	0.5	0	2

Table 1. Reactions Involving Aluminum Species (Continued)

Reaction	A, cc/ mole-sec	n	E, kcal/mole	Reference
$AlO + OH^- = AlO_2H + e$	1×10^{11}	0.5	0	2
$AlO + HNO = NO + AlOH$	3.2×10^{11}	0.5	0	36
$AlO + H_2O = OH + AlOH$	8.4×10^{11}	0.5	0	36
$AlO + NH_2 = NH + AlOH$	1.1×10^{12}	0.5	0	36
$AlO + NH_3 = NH_2 + AlOH$	6.6×10^{11}	0.5	0	36
$AlO + NaOH = NaO + AlOH$	1.4×10^{11}	0.5	0	36
$AlO + NaH = AlOH + Na$	1×10^{11}	0.5	3	2
$AlO + N = Al + ON$	5×10^{11}	0.5	6	2
$Al_2O + AlOCl = AlCl + Al_2O_2$	1×10^{11}	0.5	8	2
$Al_2O + AlO_2H = AlOH + Al_2O_2$	5×10^{10}	0.5	6	2
$Al_2O + Be^+ = Al_2O^+ + Be$	4×10^{11}	0.5	0	2
$Al_2O + BeO = Be + Al_2O_2$	1×10^{11}	0.5	6	2
$Al_2O^+ + Cl = Al^+ + AlOCl$	1×10^{11}	0.5	6	2
$Al_2O^+ + Cl^- = Al + AlOCl$	1×10^{11}	0.5	6	2
$Al_2O^+ + M + e = Al_2O + M$	5×10^{23}	-1.5	0	2
$Al_2O + F = Al + AlOF$	1×10^{11}	0.5	7	2
$Al_2O + F = AlF + AlO$	1×10^{11}	0.5	6	2
$Al_2O^+ + F = Al^+ + AlOF$	1×10^{10}	0.5	7	2
$Al_2O^+ + F^- = Al + AlOF$	1×10^{11}	0.5	7	2
$Al_2O^+ + H^- = Al + AlOH$	1×10^{11}	0.5	6	2

Table 1. Reactions Involving Aluminum Species (Continued)

Reaction	A, cc/ mole-sec	n	E, kcal/mole	Reference
$Al_2O + OH = H + Al_2O_2$	1×10^{11}	0.5	6	2
$Al_2O + Li^+ = Al_2O^+ + Li$	4×10^{11}	0.5	0	2
$Al_2O + O^- = Al_2O_2 + e$	1×10^{11}	0.5	0	2
$Al_2O^+ + O^- = Al_2O_2$	1×10^{11}	0.5	0	2
$Al_2O + O_2^- = O^- + Al_2O_2$	5×10^{10}	0.5	5	2
$Al_2O^+ + K = K^+ + Al_2O$	4×10^{11}	0.5	0	2
$Al_2O^+ + Na = Na^+ + Al_2O$	5×10^{11}	0.5	0	2
$AlOCl + Be = BeO + AlCl$	1×10^{11}	0.5	8	2
$AlOCl + F = O + AlClF$	1×10^{11}	0.5	8	2
$AlOCl + H = AlCl + OH$	1×10^{11}	0.5	8	2
$AlOCl + Li = AlO + LiCl$	1×10^{11}	0.5	8	2
$AlOCl + K = AlO + KCl$	1×10^{11}	0.5	8	2
$AlOF + Be = AlF + BeO$	1×10^{11}	0.5	8	2
$AlOF + CO = AlF + CO_2$	1×10^{11}	0.5	8	2
$AlOF + F = O + AlF_2$	1×10^{10}	0.5	8	2
$AlOF + N = AlF + NO$	1×10^{11}	0.5	6	2
$AlOF + O = AlF + O_2$	1×10^{11}	0.5	6	2
$AlOH + BeH = BeH_2 + AlO$	1×10^{11}	0.5	4	2
$AlOH + BeOH = BeO_2H_2 + Al$	1×10^{11}	0.5	5	2
$AlOH + BeO = Be + AlO_2H$	1×10^{11}	0.5	6	2

Table 1. Reactions Involving Aluminum Species (Continued)

Reaction	A, cc/ mole-sec	n	E, kcal/mole	Reference
$AlOH + BeO = BeOH + AlO$	1×10^{11}	0.5	4	2
$AlOH + CH = AlO + CH_2$	4×10^{10}	0.7	2	22
$AlOH + CN = AlO + HCN$	1×10^{11}	0.5	4	2
$AlOH + Cl = AlCl + OH$	5×10^{10}	0.5	5	2
$AlOH + Cl = AlO + HCl$	1.4×10^{11}	0.5	0	36
$AlOH + Cl = AlOCl + H$	1×10^{11}	0.5	4	2
$AlOH + F = AlOF + H$	1×10^{11}	0.5	4	2
$AlOH + F = AlF + OH$	1×10^{11}	0.5	5	2
$AlOH + F = AlO + HF$	1.8×10^{11}	0.5	0	36
$AlOH + H = AlO + H_2$	1.2×10^{11}	0.7	5	22
$AlOH + OH = AlO + H_2O$	2.1×10^{11}	0.5	0	36
$AlOH + LiO = AlO + LiOH$	1×10^{11}	0.5	4	2
$AlOH + N = AlO + NH$	1×10^{11}	0.5	4	2
$AlOH + NH = AlO + NH_2$	1×10^{11}	0.5	4	2
$AlOH + O^- = AlO_2H + e$	1×10^{11}	0.5	0	2
$AlOH + O = AlO + OH$	3.7×10^{11}	0.5	0	36
$AlOH + O^- = AlO + OH^-$	1×10^{11}	0.5	4	2
$AlOH + NaO = AlO + NaOH$	3.1×10^{11}	0.5	0	36
$AlO_2H + Be = BeOH + AlO$	1×10^{11}	0.5	5	2
$AlO_2H + BeOH = BeO_2H_2 + AlO$	1×10^{11}	0.5	5	2

Table 1. Reactions Involving Aluminum Species (Concluded)

Reaction	A, cc/ mole-sec	n	E, kcal/mole	Reference
$AlO_2H + CO = CO_2 + AlOH$	5×10^{10}	0.5	6	2
$AlO_2H + Cl = AlOCl + OH$	5×10^{10}	0.5	5	2
$AlO_2H + Cl^- = AlOCl + OH^-$	1×10^{10}	0.5	6	2
$AlO_2H + F = AlOF + OH$	1×10^{11}	0.5	5	2
$AlO_2H + F^- = AlOF + OH^-$	5×10^{10}	0.5	5	2
$AlO_2H + H = H_2O + AlO$	1×10^{10}	0.5	5	2
$AlO_2H + H = AlOH + OH$	5×10^{10}	0.5	6	2
$AlO_2H + Li = LiOH + AlO$	1×10^{11}	0.5	5	2
$AlO_2H + Li = AlOH + LiO$	1×10^{11}	0.5	6	2
$AlO_2H + N = NO + AlOH$	5×10^{10}	0.5	6	2
$AlO_2H + O = O_2 + AlOH$	5×10^{10}	0.5	6	2
$AlO_2H + K = KOH + AlO$	1×10^{11}	0.5	5	2
$AlO_2H + Na = Na\ OH + AlO$	5×10^{10}	0.5	5	2
$AlO_2H + Na = AlOH + NaO$	5×10^{10}	0.5	6	2
$Al_2O_2 + CO = Al_2O + CO_2$	5×10^{10}	0.5	6	2
$Al_2O_2 + N = NO + Al_2O$	1×10^{11}	0.5	6	2
$Al_2O_2 + O = O_2 + Al_2O$	1×10^{11}	0.5	6	2

Table 2. Reactions Involving Beryllium Species

Reaction	A, cc/ mole-sec	n	E, kcal/mole	Reference
$Be + BeO_2H_2 = 2BeOH$	1×10^{11}	0.5	5	2
$Be + HCO = BeH + CO$	1×10^{11}	0.5	2	2
$Be + CL + M = BeCl + M$	3×10^{16}	-0.5	0	2
$Be^{+} + Cl^{-} + M = BeCl + M$	4×10^{17}	-0.5	0	2
$Be + Cl_2 = BeCl + Cl$	5×10^{11}	0.5	3	2
$Be + ClF = BeCl + F$	5×10^{11}	0.5	3	2
$Be + ClF = BeF + Cl$	5×10^{11}	0.5	3	2
$Be^{+} + LiCl = BeCl + Li^{+}$	1×10^{11}	0.5	6	2
$Be^{+} + NaCl = BeCl + Na^{+}$	1×10^{11}	0.5	5	2
$Be^{+} + e + M = Be + M$	5×10^{23}	-1.5	0	2
$Be + F + M = BeF + M$	3×10^{16}	-0.5	0	2
$Be^{+} + F^{-} + M = BeF + M$	4×10^{11}	-0.5	0	2
$Be + F_2 = BeF + F$	5×10^{11}	0.5	3	2
$Be^{+} + LiF = BeF + Li^{+}$	1×10^{11}	0.5	7	2
$Be^{+} + NaF = BeF + Na^{+}$	1×10^{11}	0.5	6	2
$Be + H + M = BeH + M$	3×10^{16}	-0.5	0	2
$Be + OH + M = BeOH + M$	3×10^{16}	-0.5	0	2
$Be + HO = BeO + H$	5×10^{11}	0.5	6	2
$Be + H_2O = BeOH + H$	1×10^{11}	0.5	6	2
$Be + NaH = BeH + Na$	2.2×10^{12}	0.7	9	22

Table 2. Reactions Involving Beryllium Species (Continued)

Reaction	A, cc/ mole-sec	n	E, kcal/mole	Reference
$Be^+ + NaH = BeH + Na^+$	1×10^{11}	0.5	3	2
$Be^+ + Li = Be + Li^+$	4×10^{11}	0.5	0	2
$Be^+ + LiH = BeH + Li^+$	1×10^{11}	0.5	3	2
$Be + LiO = BeO + Li$	5×10^{11}	0.5	5	2
$Be^+ + LiO = BeO + Li^+$	1×10^{11}	0.5	5	2
$Be^+ + NO = Be + NO^+$	4×10^{11}	0.5	0	2
$Be + O^- = e + BeO$	5×10^{11}	0.5	0	2
$Be + O + M = BeO + M$	3×10^{16}	-0.5	0	2
$Be^+ + O^- + M = BeO + M$	4×10^{17}	-0.5	0	2
$Be + O_2^- = BeO + O^-$	5×10^{11}	0.5	5	2
$Be^+ + O_2^- = BeO + O$	5×10^{11}	0.5	5	2
$Be^+ + NaO = BeO + Na^+$	1×10^{11}	0.5	4	2
$Be + NaO = BeO + Na$	5×10^{11}	0.5	4	2
$Be^+ + Na = Be + Na^+$	4×10^{11}	0.5	0	2
$2BeCl = Be + BeCl_2$	1×10^{11}	0.5	6	2
$BeCl + BeF = BeClF + Be$	1×10^{11}	0.5	8	2
$BeCl + M + Cl = BeCl_2 + M$	3×10^{16}	-0.5	0	2
$BeCl + Cl^- = e + BeCl_2$	1×10^{11}	0.5	0	2
$BeCl + Cl_2 = BeCl_2 + Cl$	1×10^{11}	0.5	3	2
$BeCl + ClF = BeCl_2 + F$	1×10^{11}	0.5	3	2

Table 2. Reactions Involving Beryllium Species (Continued)

Reaction	A, cc/ mole-sec	n	E, kcal/mole	Reference
$BeCl + ClF = BeClF + Cl$	1×10^{11}	0.5	3	2
$BeCl + HCl = BeCl_2 + H$	1×10^{11}	0.5	6	2
$BeCl + LiCl = BeCl_2 + Li$	1×10^{11}	0.5	6	2
$BeCl + NaCl = BeCl_2 + Na$	1×10^{11}	0.5	5	2
$BeCl + e = Be + Cl^-$	5×10^{11}	0.5	0	2
$BeCl + F + M = BeClF + M$	3×10^{16}	-0.5	0	2
$BeCl + F_2 = BeClF + F$	1×10^{11}	0.5	2	2
$BeCl + HF = BeClF + H$	1×10^{11}	0.5	7	2
$BeCl + LiF = BeClF + Li$	1×10^{11}	0.5	7	2
$BeCl + NaF = BeClF + Na$	1×10^{11}	0.5	6	2
$BeCl + H = HCl + Be$	5×10^{11}	0.5	6	2
$BeCl + OH = BeOH + Cl$	1×10^{11}	0.5	6	2
$BeCl + Li = LiCl + Be$	5×10^{11}	0.5	6	2
$BeCl + O = Cl + BeO$	5×10^{11}	0.5	6	2
$BeCl + O^- = Cl^- + BeO$	1×10^{11}	0.5	6	2
$BeCl + Na = NaCl + Be$	5×10^{11}	0.5	6	2
$2BeF = BeF_2 + Be$	1×10^{11}	0.5	8	2
$BeF + Cl + M = BeClF + M$	3×10^{16}	-0.5	0	2
$BeF + ClF = BeF_2 + Cl$	1×10^{11}	0.5	3	2
$BeF + ClF = BeClF + F$	1×10^{11}	0.5	3	2

Table 2. Reactions Involving Beryllium Species (Continued)

Reaction	A, cc/ mole-sec	n	E, kcal/mole	Reference
$BeF + HCl = BeClF + H$	1×10^{11}	0.5	6	2
$BeF + LiCl = BeClF + Li$	1×10^{11}	0.5	6	2
$BeF + NaCl = BeClF + Na$	1×10^{11}	0.5	5	2
$BeF + F + M = BeF_2 + M$	3×10^{16}	-0.5	0	2
$BeF + F_2 = BeF_2 + F$	1×10^{11}	0.5	2	2
$BeF + HF = BeF_2 + H$	1×10^{11}	0.5	7	2
$BeF + LiF = BeF_2 + Li$	1×10^{11}	0.5	7	2
$BeF + NaF = BeF_2 + Na$	1×10^{11}	0.5	6	2
$BeF + H = Be + HF$	4×10^{11}	0.5	8	2
$BeF + HO = BeOH + F$	1×10^{11}	0.5	6	2
$BeF + Li = Be + LiF$	5×10^{11}	0.5	8	2
$BeF + O = F + BeO$	5×10^{11}	0.5	8	2
$BeF + Na = Be + NaF$	5×10^{11}	0.5	8	2
$2BeH = BeH_2 + Be$	1×10^{11}	0.5	3	2
$BeH_2 + BeO = BeH + BeOH$	1×10^{11}	0.5	5	2
$BeH + B = Be + BH$	7.0×10^{11}	0.7	3	22
$BeH + C = Be + CH$	5.8×10^{11}	0.7	8	22
$BeH + CN = Be + HCN$	1×10^{11}	0.5	3	2
$BeH_2 + CN = BeH + HCN$	1×10^{11}	0.5	5	2
$BeH + HCO = BeH_2 + CO$	1×10^{11}	0.5	2	2

Table 2. Reactions Involving Beryllium Species (Continued)

Reaction	A, cc/mole-sec	n	E, kcal/mole	Reference
$BeH + Cl = BeCl + H$	5×10^{11}	0.5	3	2
$BeH + Cl = Be + HCl$	2.6×10^{11}	0.7	3	22
$BeH_2 + Cl = BeH + HCl$	1×10^{11}	0.5	5	2
$BeH + F = Be + HF$	2.5×10^{11}	0.7	2	22
$BeH_2 + F = BeH + HF$	1×10^{11}	0.5	5	2
$BeH + H + M = BeH_2 + M$	3×10^{16}	-0.5	0	2
$BeH_2 + H = BeH + H_2$	1×10^{11}	0.5	5	2
$BeH + LiH = BeH_2 + Li$	1×10^{11}	0.5	3	2
$BeH + NH = BeH_2 + N$	1×10^{11}	0 5	5	2
$BeH + NH = Be + NH_2$	1×10^{11}	0.5	3	2
$BeH + NH_2 = BeH_2 + NH$	1×10^{11}	0.5	5	2
$BeH + OH = Be + H_2O$	1×10^{11}	0.5	3	2
$BeH_2 + OH = BeH + H_2O$	1×10^{11}	0.5	5	2
$BeH + NaK = BeH_2 + Na$	1×10^{11}	0.5	3	2
$BeH + LiO = LiOH + Be$	1×10^{11}	0.5	3	2
$BeH_2 + LiO = BeH + LiOH$	1×10^{11}	0.5	5	2
$BeH + N = Be + NH$	5×10^{11}	0.5	3	2
$BeH + O = BeO + H$	5×10^{11}	0.5	0	2
$BeH_2 + O = BeH + OH$	1×10^{11}	0.5	5	2
$BeH + O^- = Be + OH^-$	5×10^{11}	0.5	3	2

Table 2. Reactions Involving Beryllium Species (Continued)

Reaction	A, cc/ mole-sec	n	E, kcal/mole	Reference
$BeH_2 + O^- = BeH + OH^-$	1×10^{11}	0.5	5	2
$BeH + NaO = Be + NaOH$	1×10^{11}	0.5	3	2
$BeH_2 + NaO = BeH + NaOH$	1×10^{11}	0.5	5	2
$2BeO = Be_2O_2$	1×10^{11}	0.5	0	2
$BeO + BeOH = Be_2O_2 + H$	5×10^{10}	0.5	4	2
$BeO + Be_2O_2 = Be_3O_3$	1×10^{11}	0.5	0	2
$BeO + Be_3O_3 = Be_4O_4$	1×10^{11}	0.5	0	2
$Be_2O_2 + BeOH = Be_3O_3 + H$	5×10^{10}	0.5	4	2
$Be_3O_3 + BeOH = Be_4O_4 + H$	5×10^{10}	0.5	4	2
$2Be_2O = Be_4O_2$	5×10^{10}	0.5	0	2
$BeO + CO = Be + CO_2$	1×10^{11}	0.5	6	2
$BeO + HCN = CN + BeOH$	3.9×10^{11}	0.7	15	22
$BeO + HCO = CO + BeOH$	1.3×10^{11}	0.5	0	36
$BeO + CH_3 = CH_2 + BeOH$	1.6×10^{11}	0.7	1	22
$BeO + H_2CO = HCO + BeOH$	6.0×10^{11}	0.6	2	22
$BeO + CH_4 = CH_3 + BeOH$	1.13×10^{12}	0.6	4	22
$BeO + H + M = HBeO + M$	3×10^{16}	-0.5	0	2
$BeO + HCl = BeOH + Cl$	1×10^{11}	0.5	6	2
$BeO + H_2 = BeOH + H$	1×10^{11}	0.5	6	2
$BeO + LiH = BeOH + Li$	1×10^{11}	0.5	3	2

Table 2. Reactions Involving Beryllium Species (Continued)

Reaction	A, cc/ mole-sec	n	E, kcal/mole	Reference
$BeO + NH = BeOH + N$	1×10^{11}	0.5	5	2
$BeO + HO = BeOH + O$	1×10^{11}	0.5	6	2
$BeO + HO^- = BeOH + O^-$	1×10^{11}	0.5	8	2
$BeO + NaH = BeOH + Na$	1×10^{11}	0.5	3	2
$BeO + HCN = BeOH + CN$	1×10^{11}	0.5	6	2
$BeO + HCO = BeOH + CO$	1×10^{11}	0.5	2	2
$BeO + LiOH = BeOH + LiO$	1×10^{11}	0.5	6	2
$BeO + NH_2 = NH + BeOH$	1.7×10^{12}	0.5	0	36
$BeO + HNO = NO + BeOH$	3.5×10^{11}	0.5	0	36
$BeO + H_2O = BeOH + OH$	1×10^{11}	0.5	6	2
$BeO + NaOH = BeOH + NaO$	1×10^{11}	0.5	7	2
$BeO + NH_3 = NH_2 + BeOH$	1.3×10^{12}	0.5	0	36
$BeO + N = Be + NO$	5×10^{11}	0.5	6	2
$BeO + O = Be + O_2$	5×10^{11}	0.5	6.	2
$BeOH + CH = BeO + CH_2$	2×10^{11}	0.7	2	22
$BeOH + Cl = BeO + HCl$	9×10^{10}	0.5	0	36
$BeOH + F = BeO + HF$	1×10^{11}	0.5	0	36
$BeOH + H = BeO + H_2$	5×10^{11}	0.7	5	22
$BeOH + OH = BeO + H_2O$	1.1×10^{11}	0.5	0	36
$BeOH + OH = BeO_2H_2$	1×10^{11}	0.5	0	2

Table 2. Reactions Involving Beryllium Species (Concluded)

Reaction	A, cc/mole-sec	n	E, kcal/mole	Reference
$BeOH + LiOH = BeO_2H_2 + Li$	1×10^{11}	0.5	5	2
$BeOH + KOH = BeO_2H_2 + K$	1×10^{11}	0.5	5	2
$BeOH + NaOH = BeO_2H_2 + Na$	1×10^{11}	0.5	5	2
$BeOH + O = BeO + OH$	2.0×10^{11}	0.5	0	36
$BeOH + NaO = BeO + NaOH$	1.8×10^{11}	0.5	0	36
$BeO_2H_2 + H = BeOH + H_2O$	1×10^{11}	0.5	5	2

Table 3. Reactions Involving Boron Species

Reaction	A, cc/ mole-sec	n	E, kcal/mole	Reference
$B^+ + BO = B + BO^+$	4×10^{11}	0.5	0	2
$B + BF_2 = 2BF$	1×10^{11}	0.5	6	2
$B + BOF = BF + BO$	1×10^{11}	0.5	9	2
$B + BH_2 = 2\ BH$	1×10^{11}	0.5	6	2
$B + BF_3 = BF + BF_2$	1×10^{11}	0.5	8	2
$B + BH_3 = BH + BH_2$	1×10^{11}	0.5	6	2
$B + B_2O_3 = BO + B_2O_2$	1×10^{11}	0.5	8	2
$B^+ + e + M = B + M$	5×10^{23}	-1.5	0	2
$B + F + M = BF + M$	3×10^{16}	-0.5	0	2
$B^+ + F^- + M = BF + M$	4×10^{17}	-0.5	0	2
$B + F^- = e + BF$	1×10^{11}	0.5	11	2
$B + FH = BF + H$	5×10^{11}	0.5	7	2
$B + FNa = BF + Na$	5×10^{11}	0.5	6	2
$B^+ + FNa = BF + Na^+$	1×10^{11}	0.5	6	2
$B + LiH = Li + BH$	1.5×10^{12}	0.7	5	22
$B + OH^- = BO + H^-$	5×10^{10}	0.5	9	2
$B + HO = BO + H$	5×10^{11}	0.5	6	2
$B + NaH = Na + HB$	9.2×10^{11}	0.7	5	22
$B + HOH = BOH + H$	1×10^{11}	0.5	6	2
$B^+ + O + M = BO^+ + M$	5×10^{11}	0.5	0	2

Table 3. Reactions Involving Boron Species (Continued)

Reaction	A, cc/mole-sec	n	E, kcal/mole	Reference
$B + O + M = BO + M$	3×10^{16}	-0.5	0	2
$B^+ + O^- + M = BO + M$	4×10^{17}	-0.5	0	2
$B + O^- = e + BO$	1×10^{11}	0.5	11	2
$B^+ + O_2^- = BO + O$	5×10^{11}	0.5	5	2
$B^+ + O_2 = BO^+ + O$	5×10^{11}	0.5	9	2
$B + O_2 = BO + O$	5×10^{11}	0.5	6	2
$B + O_2^- = BO + O^-$	5×10^{11}	0.5	5	2
$B^+ + NaO = BO^+ + Na$	5×10^{11}	0.5	4	2
$B^+ + NaO = BO + Na^+$	1×10^{11}	0.5	5	2
$B + NaO = BO + Na$	5×10^{11}	0.5	4	2
$B^+ + Na = B + Na^+$	4×10^{11}	0.5	0	2
$BF + B_2O_3 = OBF + B_2O_2$	1×10^{11}	0.5	8	2
$BF + F^- = e + BF_2$	1×10^{11}	0.5	0	2
$BF + HO = OBF + H$	1×10^{11}	0.5	6	2
$BF + O^- = e + FBO$	1×10^{11}	0.5	0	2
$BF + O^- = F^- + BO$	1×10^{11}	0.5	16	2
$BF + O_2 = OBF + O$	1×10^{11}	0.5	6	2
$BF + O_2^- = OBF + O^-$	1×10^{11}	0.5	5	2
$2BF_2 = BF + BF_3$	1×10^{11}	0.5	6	2
$BF_2 + BO = BFO + BF$	1×10^{11}	0.5	6	2

Table 3. Reactions Involving Boron Species (Continued)

Reaction	A, cc/mole-sec	n	E, kcal/mole	Reference
$BF_2 + F = BF_3$	1×10^{11}	0.5	0	2
$BF_2 + F^- = e + BF_3$	1×10^{11}	0.5	0	2
$BF_2 + NaF = Na + BF_3$	1×10^{11}	0.5	6	2
$BF_2 + H = BF + FH$	1×10^{11}	0.5	6	2
$BF_2 + O = OBF + F$	1×10^{11}	0 5	6	2
$BF_2 + Na = BF + FNa$	1×10^{11}	0.5	6	2
$BH + BH_3 = 2BH_2$	1×10^{11}	0.5	4	2
$BH + C = B + CH$	1.1×10^{12}	0.7	3	22
$BH + CH_2 = CH + BH_2$	1.05×10^{12}	0.7	27	22
$BH + CH_3 = CH_2 + BH_2$	4.3×10^{11}	0.7	4	22
$BH + CH_4 = CH_3 + BH_2$	2.1×10^{12}	0.6	10	22
$BH + HCN = CN + BH_2$	1.12×10^{12}	0.6	19	22
$BH + H_2CO = HCO + BH_2$	1.11×10^{12}	0.6	9	22
$BH + HCO = CO + BH_2$	2.1×10^{11}	0.5	0	36
$BH + Cl = B + HCl$	2.4×10^{11}	0.7	5	22
$BH + F = B + HF$	2.3×10^{11}	0.7	4	22
$BH + H + M = BH_2 + M$	3×10^{16}	-0.5	0	2
$BH + H = B + H_2$	1.4×10^{12}	0.7	2	22
$BH + NH_2 = NH + BH_2$	5.2×10^{11}	0.6	6	22
$BH + NH_3 = NH_2 + BH_2$	7.1×10^{11}	0.6	4	22

Table 3. Reactions Involving Boron Species (Continued)

Reaction	A, cc/mole-sec	n	E, kcal/mole	Reference
$BH + HNO = NO + BH_2$	1.2×10^{12}	0.5	0	36
$BH + O = B + OH$	6.6×10^{11}	0.7	1	22
$BH_2 + H = BH_3$	1×10^{11}	0.5	0	2
$BH_2 + H = BH + H_2$	1×10^{11}	0.5	6	2
$BH_2 + H_2 = BH_3 + H$	1×10^{11}	0.5	6	2
$2BO = B_2O_2$	1×10^{11}	0.5	0	2
$BO + CH_2 = CH + HBO$	4.1×10^{11}	0.5	0	36
$BO + CH_3 = CH_2 + HBO$	6.3×10^{11}	0.6	6	22
$BO + CH_4 = CH_3 + HBO$	1.2×10^{12}	0.6	16	22
$BO + HCO = CO + HBO$	1.4×10^{11}	0.5	0	36
$BO + H_2CO = HCO + HBO$	5.5×10^{11}	0.6	16	22
$BO^+ + e + M = BO + M$	5×10^{23}	-1.5	0	2
$BO^+ + F^- + M = FBO + M$	4×10^{17}	-0.5	0	2
$BO + F = BF + O$	1×10^{11}	0.5	11	2
$BO + F^- = e + FBO$	1×10^{11}	0.5	0	2
$BO + FH = FBO + H$	1×10^{11}	0.5	7	2
$BO + FNa = FBO + Na$	1×10^{11}	0.5	6	2
$BO^+ + H^- + M = HBO + M$	4×10^{17}	-0.5	0	2
$BO + H^- = HBO + e$	1×10^{11}	0.5	0	2
$BO + H_2 = HBO + H$	1×10^{11}	0.5	6	2

Table 3. Reactions Involving Boron Species (Continued)

Reaction	A, cc/mole-sec	n	E, kcal/mole	Reference
$BO^+ + OH^- = HBO_2$	1×10^{11}	0.5	0	2
$BO + HO = HBO + O$	1×10^{11}	0.5	6	2
$BO + HO^- = HBO + O^-$	1×10^{11}	0.5	6	2
$BO + HO = HBO_2$	1×10^{11}	0.5	0	2
$BO + HO^- = e + HBO_2$	1×10^{11}	0.5	0	2
$BO + HNa = HBO + Na$	1×10^{11}	0.5	3	2
$BO + H_2O = HBO + OH$	1×10^{11}	0.5	6	2
$BO + NaOH = HBO + NaO$	1×10^{11}	0.5	7	2
$BO + NaOH = Na + HBO_2$	1×10^{11}	0.5	5	2
$BO^+ + Na = BO + Na^+$	4×10^{11}	0.5	0	2
$B_2O_2 + OH = H + B_2O_3$	1×10^{11}	0.5	6	2
$B_2O_2 + O = B_2O_3$	1×10^{11}	0.5	0	2
$B_2O_2 + O^- = e + B_2O_3$	1×10^{11}	0.5	0	2
$B_2O_2 + O_2 = B_2O_3 + O$	1×10^{11}	0.5	6	2
$B_2O_2 + O_2^- = O^- + B_2O_3$	1×10^{11}	0.5	5	2
$B_2O_2 + NaO = Na + B_2O_3$	1×10^{11}	0.5	4	2
$HBO + CH = BO + CH_2$	4.4×10^{11}	0.5	0	36
$HBO + CN = BO + HCN$	3.1×10^{11}	0.5	0	36
$HBO + F = BO + FH$	1×10^{11}	0.5	6	2
$HBO + F = FBO + H$	1×10^{11}	0.5	6	2

Table 3. Reactions Involving Boron Species (Concluded)

Reaction	A, cc/ mole-sec	n	E, kcal/mole	Reference
$HBO + F = BF + HO$	1×10^{11}	0.5	6	2
$HBO + O_2^- = O^- + HBO_2$	1×10^{11}	0.5	5	2
$HBO + O_2 = O + HBO_2$	1×10^{11}	0.5	6	2
$HBO + NaO = Na + HBO_2$	1×10^{11}	0.5	4	2
$HBO_2 + H = H_2O + BO$	1×10^{11}	0.5	4	2
$HBO_2 + H = BOH + OH$	1×10^{11}	0.5	7	2
$HBO_2 + F = FBO + OH$	1×10^{11}	0.5	7	2
$HBO_2 + F^- = FBO + OH^-$	5×10^{10}	0.5	7	2

Table 4. Reactions Involving Carbon And Carbon-Hydrogen Species

Reaction	A, cc/mole-sec	n	E, kcal/mole	Reference
$C + C + M = C_2 + M$	1×10^{16}	-0.5	0	2
$C + C_2 + M = C_3 + M$	1×10^{16}	-0.5	0	2
$C + C_2H = C_2 + CH$	5×10^{11}	0.5	4	2
$C + H_2C = 2CH$	5×10^{11}	0.5	18	2
$C + CH_4 = CH + CH_3$	5×10^{11}	0.5	6	2
$C + CH_2O = CHO + CH$	3×10^{10}	0.5	3	11
$C + HCO = CO + HC$	5×10^{11}	0.5	4	2
$C + CO_2 = 2CO$	5×10^{11}	0.5	4	2
$C + H + M = CH + M$	2×10^{16}	-0.5	0	1
$C + OH + M = CHO + M$	3×10^{15}	-0.5	0	2
$C + OH = CO + H$	5×10^{11}	0.5	4	2
$C + LiH = Li + CH$	1.7×10^{12}	0.7	9	22
$C + O + M = CO + M$	1×10^{16}	-0.5	0	2
$C + O_2 = CO + O$	5×10^{11}	0.5	4	2
$2C_2 = C_3 + C$	5×10^{11}	0.5	6	2
$C_2 + CH = H + C_3$	5×10^{11}	0.5	6	2
$C_2 + CHO = CO + C_2H$	5×10^{11}	0.5	6	2
$C_2 + CH_2O = CHO + C_2H$	2×10^{10}	0.5	6	11
$C_2 + H = C + CH$	5×10^{11}	0.5	10	1
$C_2 + H = C_2H$	5×10^{11}	0.5	0	1

Table 4. Reactions Involving Carbon And Carbon-Hydrogen Species (Continued)

Reaction	A, cc/ mole-sec	n	E, kcal/mole	Reference
$C_2 + O = CO + C$	5×10^{11}	0.5	4	2
$C_3 + OH = C_2 + CHO$	1×10^{10}	0.5	10	2
$C_3 + O = C_2 + CO$	5×10^{11}	0.5	4	2
$CH + C_2H = C + C_2H_2$	5×10^{11}	0.5	6	2
$CH + C_2H = C_2 + CH_2$	1×10^{11}	0.5	40	1
$2CH = C_2H_2$	5×10^{11}	0.5	6	2
$CH + CH_2 = C + CH_3$	5×10^{11}	0.5	6	2
$CH + CH_3 = 2CH_2$	1.2×10^{11}	0.7	5	22
$CH + CH_4 = CH_3 + CH_2$	2.4×10^{11}	0.7	6	22
$CH + CH_4 = CH_3 + CH_2$	5×10^{11}	0.5	6	2
$CH + HCN = CN + CH_2$	3.3×10^{11}	0.6	8	22
$CH + CHO = CO + CH_2$	5×10^{11}	0.5	6	2
$CH + CH_2O = CHO + CH_2$	2×10^{10}	0.5	5	11
$CH + H_2CO = HCO + CH_2$	1.1×10^{11}	0.7	4	22
$CH + HCO = CO + CH_2$	3×10^{10}	0.7	1	22
$CH + CO_2 = CO + CHO$	1×10^{10}	0.5	6	2
$CH + Cl = C + HCl$	3.2×10^{11}	0.7	1	22
$CH + F = C + HF$	3.0×10^{11}	0.7	1	22
$CH + H = C + H_2$	6.4×10^{11}	0.7	2	22
$CH + H = CH_2$	5×10^{11}	0.5	0	1

Table 4. Reactions Involving Carbon And Carbon-Hydrogen Species (Continued)

Reaction	A, cc/ mole-sec	n	E, kcal/mole	Reference
$CH + NH_2 = NH + CH_2$	3×10^{10}	0.7	2	22
$CH + NH_3 = NH_2 + CH_2$	5×10^{10}	0.7	2	22
$CH + OH = H + CHO$	5×10^{11}	0.5	10	2
$CH + OH = C + H_2O$	5×10^{11}	0.5	6	2
$CH + HNO = NO + CH_2$	6.3×10^{11}	0.5	0	36
$CH + HO_2 = O_2 + CH_2$	1×10^{10}	0.5	15	2
$CH + HO_2 = OH + CHO$	5×10^{11}	0.5	6	2
$CH + NaOH = NaO + CH_2$	9.9×10^{11}	0.6	5	22
$CH + N = C + NH$	4.5×10^{11}	0.7	2	22
$CH + O = C + OH$	2.5×10^{11}	0.7	2	22
$CH + O^- = HCO + e$	1×10^{11}	0.5	0	2
$CH + O + M = CHO + M$	1×10^{16}	-0.5	0	2
$CH + O = H + CO$	5×10^{11}	0.5	4	2
$CH + O_2 = O + CHO$	5×10^{11}	0.5	6	2
$2C_2H = C_2 + C_2H_2$	1×10^{10}	0.5	6	2
$C_2H + H = C_2 + H_2$	5×10^{11}	0.5	35	1
$C_2H + H = C_2H_2$	5×10^{11}	0.5	0	1
$C_2H + H = 2CH$	5×10^{11}	0.5	50	2
$C_2H + CH_2 = CH + C_2H_2$	5×10^{11}	0.5	6	2
$C_2H + CH_2 = C_2 + CH_3$	1×10^{11}	0.5	6	2

Table 4. Reactions Involving Carbon And Carbon-Hydrogen Species (Continued)

Reaction	A, cc/mole-sec	n	E, kcal/mole	Reference
$C_2H + CH_3 = C_2 + CH_4$	1×10^{11}	0.5	6	2
$C_2H + CH_3 = CH_2 + C_2H_2$	1×10^{11}	0.5	6	2
$C_2H + CHO = CO + C_2H_2$	1×10^{11}	0.5	6	2
$C_2H + CH_2O = CHO + C_2H_2$	3×10^{10}	0.5	6	11
$C_2H + CH_4 = CH_3 + C_2H_2$	1×10^{10}	0.5	6	11
$C_2H + OH = O + C_2H_2$	5×10^{11}	0.5	6	2
$C_2H + OH = C_2 + H_2O$	5×10^{11}	0.5	6	2
$C_2H + H_2O = C_2H_2 + OH$	1×10^{10}	0.5	6	2
$C_2H + O = CH + CO$	5×10^{11}	0.5	4	2
$C_2H + O = C_2 + OH$	5×10^{11}	0.5	4	2
$C_2H_2 + H = C_2H + H_2$	5×10^{11}	0.5	15	1
$2CH_2 = CH + CH_3$	5×10^{11}	0.5	6	2
$CH_2 + CH_4 = 2CH_3$	1.21×10^{12}	0.7	20	11,22
$CH_2 + HCO = CO + CH_3$	3×10^{10}	0.7	1	22
$CH_2 + CH_2O = CHO + CH_3$	3×10^{10}	0.5	6	11
$CH_2 + Cl = CH + HCl$	3.6×10^{11}	0.7	29	22
$CH_2 + F = CH + HF$	8×10^{10}	0.7	5	22
$CH_2 + H = CH + H_2$	2.9×10^{11}	0.7	26	1,22
$CH_2 + H_2 = H + CH_3$	1×10^{10}	0.5	10	11
$CH_2 + OH = O + CH_3$	5×10^{11}	0.5	6	2

Table 4. Reactions Involving Carbon And Carbon-Hydrogen Species (Continued)

Reaction	A, cc/mole-sec	n	E, kcal/mole	Reference
$CH_2 + OH = CH + H_2O$	5×10^{11}	0.5	6	2
$CH_2 + HNO = NO + CH_3$	6.8×10^{11}	0.5	0	36
$CH_2 + H_2O = OH + CH_3$	1×10^{10}	0.5	10	2
$CH_2 + O = CH + OH$	3.2×10^{11}	0.7	26	2
$CH_2 + O = H + CHO$	5×10^{11}	0.5	4	2
$CH_2 + O_2 = H_2CO + O$	5×10^{11}	0.5	7	2
$CH_3 + CN = CH_2 + HCN$	9×10^{10}	0.7	3	22
$CH_3 + HCO = CH_2 + H_2CO$	1.5×10^{11}	0.7	4	22
$CH_3 + HCO = CO + CH_4$	3.0×10^{11}	0.5	0	36
$CH_3 + H_2CO = CHO + CH_4$	1×10^{10}	0.5	6	12
$CH_3 + Cl = CH_2 + HCl$	2.2×10^{11}	0.7	8	22
$CH_3 + F = CH_2 + HF$	6×10^{10}	0.7	1	22
$CH_3 + H = CH_2 + H_2$	1.8×10^{11}	0.7	3	22
$CH_3 + H = CH_4$	5×10^{11}	0.5	0	2
$CH_3 + H_2 = H + CH_4$	1×10^{10}	0.5	10	12
$CH_3 + NH = CH_2 + NH_2$	9×10^{10}	0.7	2	22
$CH_3 + NH_2 = CH_2 + NH_3$	1.7×10^{11}	0.7	2	22
$CH_3 + HNO = NO + CH_4$	5.0×10^{11}	0.5	0	36
$CH_3 + OH = CH_2 + H_2O$	6×10^{10}	0.7	2	22
$CH_3 + HO_2 = CH_4 + O_2$	1×10^{11}	0.5	6	2

Table 4. Reactions Involving Carbon And Carbon-Hydrogen Species (Concluded)

Reaction	A, cc/mole-sec	n	E, kcal/mole	Reference
$CH_3 + O = CH_2O + H$	1.9×10^{13}	0.0	0	16
$CH_3 + O = CH_2 + OH$	1×10^{11}	0.5	17	2
$CH_3 + NaO = CH_2 + NaOH$	1.3×10^{12}	0.5	0	36
$CH_4 + CN = CH_3 + HCN$	2.9×10^{11}	0.7	5	22
$CH_4 + HCO = CH_3 + H_2CO$	8.6×10^{11}	0.6	9	22
$CH_4 + Cl = CH_3 + HCl$	6.9×10^{11}	0.6	13	22
$CH_4 + F = CH_3 + HF$	9×10^{10}	0.7	1	22
$CH_4 + H = CH_3 + H_2$	4.4×10^{11}	0.7	7	22
$CH_4 + NH = CH_3 + NH_2$	5.9×10^{11}	0.6	7	22
$CH_4 + NH_2 = CH_3 + NH_3$	9.5×10^{11}	0.6	8	22
$CH_4 + OH = CH_3 + H_2O$	3.5×10^{14}	0.0	9	16
$CH_4 + O = CH_3 + OH$	4.0×10^{11}	0.5	8	37
$CH_4 + NaO = CH_3 + NaOH$	1.6×10^{11}	0.7	1	22

Table 5. Reactions Involving Carbon-Nitrogen And Carbon-Oxygen Species

Reaction	A, cc/mole-sec	n	E, kcal/mole	Reference
$CN + CHO = HCN + CO$	1.9×10^{11}	0.5	0	36
$CN + H_2CO = HCO + HCN$	1.2×10^{11}	0.7	3	22
$CN + Cl^- = CN^- + Cl$	5×10^{11}	0.5	0	2
$CN + HCl = HCN + Cl$	1×10^{11}	0.5	6	2
$CN^- + F = F^- + CN$	4×10^{11}	0.5	0	2
$CN + H + M = HCN + M$	3×10^{16}	-0.5	0	2
$CN^- + H = HCN + e$	1×10^{11}	0.5	0	2
$CN + H^- = CN^- + H$	4×10^{11}	0.5	0	2
$CN + H^- = HCN + e$	5×10^{11}	0.5	0	2
$CN + H_2 = HCN + H$	1×10^{11}	0.5	6	2
$CN + NH = HCN + N$	1×10^{11}	0.5	2	2
$CN + NH_2 = HCN + NH$	5×10^{10}	0.7	2	22
$CN + NH_3 = HCN + NH_2$	7×10^{10}	0.7	2	22
$CN + OH = HCN + O$	1×10^{11}	0.5	6	2
$CN + OH^- = CN^- + OH$	4×10^{11}	0.5	0	2
$CN + HNO = HCN + NO$	3.8×10^{11}	0.5	0	36
$CN^- + H_3O^+ = HCN + H_2O$	1×10^{11}	0.5	0	2
$CN + NaH = HCN + Na$	1×10^{11}	0.5	3	2
$CN + HO^- = HCN + O^-$	1×10^{11}	0.5	9	2
$CN + O^- = CN^- + O$	5×10^{11}	0.5	0	2

Table 5. Reactions Involving Carbon-Nitrogen And Carbon-Oxygen Species (Continued)

Reaction	A, cc/mole-sec	n	E, kcal/mole	Reference
$CN + O_2^- = CN^- + O_2$	4×10^{11}	0.5	0	2
$HCN + Cl = CN + HCl$	4.5×10^{11}	0.6	20	22
$HCN + F = CN + HF$	4×10^{10}	0.7	1	22
$HCN + H = CN + H_2$	2.6×10^{11}	0.7	18	22
$HCN + OH = CN + H_2O$	2.0×10^{11}	0.6	5	22
$HCN + LiO = CN + LiOH$	1×10^{11}	0.5	6	2
$HCN + O = CN + OH$	2.8×10^{11}	0.7	17	22
$HCN + NaO = CN + NaOH$	3.6×10^{11}	0.6	2	22
$CO + C_2O = C_2 + CO_2$	1×10^{11}	0.5	6	2
$CO + H^- = CHO + e$	5×10^{11}	0.5	0	2
$CO + OH = H + CO_2$	3×10^{11}	0.0	0.6	38
$CO + HNO = HN + CO_2$	1×10^{11}	0.5	7	2
$CO + LiO = CO_2 + Li$	1×10^{11}	0.5	5	2
$CO + NO_2 = NO + CO_2$	2×10^{11}	0.5	5	2
$CO + N_2O = N_2 + CO_2$	1×10^{11}	0.5	3	2
$CO + O + M = CO_2 + M$	1×10^{16}	0.0	3.5	26
$CO + O^- = CO_2 + e$	1×10^{11}	0.5	0	2
$CO + O_2 = O + CO_2$	3.5×10^{12}	0.0	51	39
$CO + NaO = CO_2 + Na$	1×10^{11}	0.5	4	2
$C_2O + M = CO + C + M$	1×10^{17}	0.0	100	2
$C_2O + O = 2CO$	5×10^{11}	0.5	4	2

Table 5. Reactions Involving Carbon-Nitrogen And Carbon-Oxygen Species (Continued)

Reaction	A, cc/mole-sec	n	E, kcal/mole	Reference
$CO_2 + H_2 = CO + H_2O$	1×10^{9}	0.5	15	2
$CO_2 + N = CO + NO$	2×10^{11}	0.5	8	2
$CO_2 + O = CO + O_2$	5×10^{11}	0.5	8	2
$CHO + M = CO + H + M$	1×10^{15}	0.5	23	6
$2HCO = CO + H_2CO$	1.4×10^{11}	0.5	0	36
$HCO + Cl = CO + HCl$	9×10^{10}	0.5	0	36
$CHO^{+} + e + M = CHO + M$	5×10^{23}	-1.5	0	2
$HCO + F = CO + HF$	1.1×10^{11}	0.5	0	36
$HCO + H = CO + H_2$	1.5×10^{12}	0.5	0	36
$HCO + NH = CO + NH_2$	1.4×10^{11}	0.5	0	36
$HCO + NH_2 = CO + NH_3$	2.6×10^{11}	0.5	0	36
$HCO + NH_2 = NH + H_2CO$	1.3×10^{11}	0.6	4	22
$HCO + NH_3 = NH_2 + H_2CO$	3.0×10^{11}	0.6	3	22
$HCO + HNO = NO + H_2CO$	3.2×10^{11}	0.5	0	36
$HCO + OH = CO + H_2O$	1.1×10^{11}	0.5	0	36
$CHO + Li = CO + LiH$	1×10^{11}	0.5	2	2
$CHO + Li^{+} = CHO^{+} + Li$	4×10^{11}	0.5	0	2
$CHO + N = CO + NH$	2×10^{11}	0.5	2	2
$CHO + NO = CO + HNO$	2×10^{11}	0.5	2	2
$HCO + O = CO + OH$	1.8×10^{11}	0.5	0	36

Table 5. Reactions Involving Carbon-Nitrogen And Carbon-Oxygen Species (Concluded)

Reaction	A, cc/mole-sec	n	E, kcal/mole	Reference
$CHO + O^- = CO + OH^-$	1×10^{11}	0.5	2	2
$HCO + NaO = CO + NaOH$	1.8×10^{11}	0.5	0	36
$CHO + Na = CO + NaH$	1×10^{11}	0.5	2	2
$CH_2O = H + CHO$	3×10^{17}	0.0	87	7
$H_2CO + Cl = HCO + HCl$	3.5×10^{11}	0.6	11	22
$H_2CO + F = HCO + HF$	4.1×10^{11}	0.5	0	36
$H_2CO + H = CHO + H_2$	1×10^{13}	0.0	2	6
$H_2CO + OH = HCO + H_2O$	5×10^{10}	0.7	1	22
$H_2CO + O = HCO + OH$	4.0×10^{11}	0.6	4	22
$H_2CO + NaO = HCO + NaOH$	7.2×10^{11}	0.5	0	36

Table 6. Reactions Involving Lithium Species

Reaction	A, cc/mole-sec	n	E, kcal/mole	Reference
$Li + Cl + M = ClLi + M$	3×10^{16}	-0.5	0	2
$Li^{+} + Cl^{-} + M = LiCl + M$	4×10^{17}	-0.5	0	2
$Li + Cl_2 = LiCl + Cl$	5×10^{11}	0.5	3	2
$Li^{+} + e + M = Li + M$	5×10^{23}	-1.5	0	2
$Li + M + F = LiF + M$	3×10^{16}	-0.5	0	2
$Li^{+} + F^{-} + M = LiF + M$	4×10^{17}	-0.5	0	2
$Li + F_2 = LiF + F$	5×10^{11}	0.5	2	2
$Li + H + M = LiH + M$	3×10^{16}	-0.5	0	2
$Li^{+} + H^{-} + M = LiH + M$	4×10^{17}	-0.5	0	2
$Li + H^{-} = e + LiH$	5×10^{11}	0.5	0	2
$Li + HCl = LiCl + H$	1×10^{11}	0.5	6	2
$Li^{+} + OH^{-} + M = LiOH + M$	4×10^{17}	-0.5	0	2
$Li + OH + M = LiOH + H$	3×10^{16}	-0.5	0	2
$Li + OH = LiO + H$	5×10^{11}	0.5	6	2
$Li + HOH = LiOH + H$	1×10^{11}	0.5	6	2
$Li + H_3O^{+} = Li^{+} + H + H_2O$	1×10^{11}	0.5	0	2
$Li + NO^{+} = Li^{+} + NO$	4×10^{11}	0.5	0	2
$Li^{+} + O^{-} + M = LiO + M$	4×10^{17}	-0.5	0	2
$Li + O + M = LiO + M$	3×10^{16}	-0.5	0	2
$Li^{+} + O_2^{-} = LiO + O$	5×10^{12}	0.5	5	2
$LiCl + O^{-} = LiO + Cl^{-}$	1×10^{11}	0.5	6	2

Table 6. Reactions Involving Lithium Species (Continued)

Reaction	A, cc/mole-sec	n	E, kcal/mole	Reference
$LiF + H = HF + Li$	1×10^{11}	0.5	7	2
$LiH + Cl = Li + HCl$	2.0×10^{11}	0.7	12	22
$LiH + Cl = H + LiCl$	5×10^{11}	0.5	3	2
$LiH + F = H + LiF$	5×10^{11}	0.5	3	2
$LiH + F = Li + HF$	2.4×10^{11}	0.7	8	22
$LiH + H = Li + H_2$	9.6×10^{11}	0.7	6	22
$LiH + NH = Li + NH_2$	1×10^{11}	0.5	3	2
$LiH + OH = Li + H_2O$	1×10^{11}	0.5	3	2
$LiH + LiO = Li + LiOH$	1×10^{11}	0.5	3	2
$LiH + NaO = Li + NaOH$	1×10^{11}	0.5	3	2
$LiH + O = Li + OH$	5.1×10^{11}	0.7	6	22
$LiOH + F = HF + LiO$	1×10^{11}	0.5	7	2
$LiO + Cl = LiCl + O$	5×10^{11}	0.5	5	2
$LiO + HCl = LiOH + Cl$	1×10^{11}	0.5	6	2
$LiO + F = LiF + O$	5×10^{11}	0.5	5	2
$LiO + F^- = LiF + O^-$	1×10^{11}	0.5	6	2
$LiO + H = LiH + O$	1×10^{11}	0.5	5	2
$LiO + H^- = Li + OH^-$	5×10^{11}	0.5	5	2
$LiO + H_2 = LiOH + H$	1×10^{11}	0.5	6	2
$LiO + NH = LiOH + N$	1×10^{11}	0.5	5	2

Table 6. Reactions Involving Lithium Species (Concluded)

Reaction	A, cc/mole-sec	n	E, kcal/mole	Reference
$LiO + NH_2 = LiOH + NH$	1×10^{11}	0.5	5	2
$LiO + OH = LiOH + O$	1×10^{11}	0.5	5	2
$LiO + OH^- = LiOH + O^-$	1×10^{11}	0.5	9	2
$LiO + H_2O = LiOH + OH$	1×10^{11}	0.5	6	2
$LiO + NaH = LiOH + Na$	1×10^{11}	0.5	3	2
$LiO + N = Li + NO$	5×10^{11}	0.5	5	2
$LiO + O = Li + O_2$	5×10^{11}	0.5	5	2
$LiO + O^- = Li + O_2^-$	5×10^{11}	0.5	5	2

Table 7. Reactions Involving Nitrogen Species

Reaction	A, cc/ mole-sec	n	E, kcal/mole	Reference
$N + N_2 = 3N$	4×10^{16}	-0.5	225	30
$N + NH = H + N_2$	5×10^{11}	0.5	2	13
$N + NH_2 = 2NH$	5×10^{11}	0.5	2	13
$N + NH_3 = NH_2 + NH$	5×10^{11}	0.5	2	13
$N + HNO = NH + NO$	1×10^{11}	0.5	2	2
$HNO + N = H + N_2O$	5×10^{10}	0.5	3	2
$N + H + M = NH + M$	3×10^{16}	-0.5	0	2
$N + OH + M = HNO + M$	1×10^{15}	-0.5	100	2
$N + OH = H + NO$	5×10^{11}	0.5	5	2
$N + NO = 2N + O$	1.12×10^{20}	-1.0	151	5,25
$N + O^- = NO + e$	1×10^{11}	0.5	0	2
$N + O_2 = O + NO$	1.33×10^{10}	1.0	7	25
$N + O_2^- = NO + O^-$	5×10^{11}	0.5	6	2
$N + NaO = NO + Na$	5×10^{11}	0.5	4	2
$2N_2 = 2N + N_2$	5.4×10^{17}	-0.5	225	30
$N_2 + Ar = 2N + Ar$	4×10^{16}	-0.5	225	30
$N_2 + M = 2N + M$	1.9×10^{19}	-1.0	225	5
$N_2 + NO = 2N + NO$	1.5×10^{16}	-0.5	225	30
$N_2 + NO = N + O + N_2$	5.6×10^{18}	-1.0	151	5,25

Table 7. Reactions Involving Nitrogen Species (Continued)

Reaction	A, cc/ mole-sec	n	E, kcal/mole	Reference
$N_2 + NO = N_2O + N$	8×10^7	0.0	121	5
$N_2 + NO_2 = N_2O + NO$	1.4×10^{14}	0.0	83	5
$N_2 + O = NO + N$	6.8×10^{13}	0.0	75	5
$N_2 + O = 2N + O$	1.5×10^{16}	-0.5	225	30
$N_2 + e + O = O^- + N_2$	3×10^{16}	0.0	0	42
$N_2 + O_2 = 2N + O_2$	1.5×10^{16}	-0.5	225	30
$N_2 + O_2 = N_2O + O$	4×10^{12}	0.0	106	5
$N_2 + O_2 = 2NO$	2×10^{14}	0.0	122	5
$N_2 + O_2 = NO_2 + N$	1.7×10^{11}	0.0	136	5
$N_2 + O_2 + e = O_2^- + N_2$	3×10^{16}	0.0	0	43
$NH + Cl = N + HCl$	2.2×10^{12}	0.68	0.2	22
$NH + F = N + HF$	1.4×10^{12}	0.68	0.6	22
$NH + H + M = NH_2 + M$	2×10^{16}	-0.5	0	13
$NH + H = N + H_2$	1.0×10^{12}	0.68	1.9	22
$NH + H^- = NH_2 + e$	5×10^{11}	0.5	0	2
$NH + HNO = NO + NH_2$	2×10^{11}	0.5	2	13
$NH + HO = N + H_2O$	5×10^{11}	0.5	2	2
$NH + NaH = NH_2 + Na$	1×10^{11}	0.5	3	2
$N_2O + NH = N_2 + HNO$	1×10^{11}	0.5	3	2
$NO_2 + NH = NO + HNO$	2×10^{11}	0.5	5	2
$NH + O + M = HNO + M$	1×10^{16}	-0.5	0	2

Table 7. Reactions Involving Nitrogen Species (Continued)

Reaction	A, cc/ mole-sec	n	E, kcal/mole	Reference
$NH + O = H + NO$	5×10^{11}	0.5	5	13
$NH + O = N + OH$	8.4×10^{12}	0.7	0.1	22
$NH + O^- = N + OH^-$	5×10^{11}	0.5	5	2
$NH + NaO = NaOH + N$	1×10^{11}	0.5	5	2
$NH_2 + Cl = NH + HCl$	5.1×10^{11}	0.5	0	36
$NH_2 + F = NH + HF$	6.2×10^{11}	0.5	0	36
$NH_2 + H = NH + H_2$	1.4×10^{11}	0.7	4	22
$NH_2 + H = H_2 + NH$	5×10^{11}	0.5	2	13
$NH_2 + H = NH_3$	5×10^{11}	0.5	0	2
$2NH_2 = NH + NH_3$	1×10^{12}	0.5	3	2,14
$NH_2 + HNO = NO + NH_3$	6.1×10^{11}	0.5	0	13,36
$NH_2 + OH = NH + H_2O$	3×10^{10}	0.7	1	22
$NH_2 + O^- = NH + OH^-$	1×10^{11}	0.5	5	2
$NH_2 + O = NH + OH$	9.2×10^{11}	0.5	0	36
$NH_2 + NaO = NH + NaOH$	1.2×10^{12}	0.5	0	36
$NH_3 + Cl = NH_2 + HCl$	4.5×10^{11}	0.5	0	36
$NH_3 + F = NH_2 + HF$	4.3×10^{11}	0.5	0	36
$NH_3 + H = NH_2 + H_2$	1.9×10^{11}	0.7	3	22
$NH_3 + OH = NH_2 + H_2O$	4×10^{10}	0.7	1	22
$NH_3 + H = NH_2 + H_2$	5×10^{11}	0.5	2	13

Table 7. Reactions Involving Nitrogen Species (Continued)

Reaction	A, cc/mole-sec	n	E, kcal/mole	Reference
$NH_3 + O = NH_2 + OH$	8.2×10^{11}	0.5	0	36
$NH_3 + NaO = NH_2 + NaOH$	9.6×10^{11}	0.5	0	36
$HNO + Cl = NO + HCl$	2.5×10^{11}	0.5	0	36
$HNO + F = NO + HF$	2.4×10^{11}	0.5	0	36
$HNO + H = NH + OH$	2×10^{11}	0.5	13	2
$HNO + H = NO + H_2$	3.9×10^{12}	0.5	0	13,36
$HNO + OH = NO + H_2O$	2×10^{11}	0.5	2	3
$HNO + O = NH + O_2$	1×10^{11}	0.5	7	2
$HNO + O = H + NO_2$	5×10^{10}	0.5	3	2
$HNO + O = NO + OH$	5.0×10^{11}	0.5	0	36
$HNO + NaO = NO + NaOH$	4.7×10^{11}	0.5	0	36
$NO + Ar = N + O + Ar$	5.6×10^{18}	-1.0	151	5,25
$NO^+ + e + M = NO + M$	5×10^{23}	-1.5	0	2
$NO^+ + e = N + O$	2.8×10^{20}	-1.2	0	44
$NO + e = NO^+ + 2e$	2.5×10^{13}	0.5	214	5
$NO + M = N + O + M$	2.4×10^{17}	-0.5	150	5
$NO + M = NO^+ + e + M$	6×10^{4}	1.5	214	5
$NO + H + M = HNO + M$	1×10^{17}	-0.5	0.7	2,15
$2NO = N_2O + O$	3.5×10^{12}	0.0	64	5
$2NO = NO_2 + N$	1×10^{10}	0.0	88	5

Table 7. Reactions Involving Nitrogen Species (Concluded)

Reaction	A, cc/mole-sec	n	E, kcal/mole	Reference
$2NO = N + O + NO$	1.12×10^{20}	-1.0	151	5,25
$NO + O = N + 2O$	1.12×10^{20}	-1.0	151	5,25
$NO^+ + O^- = NO + O$	3.6×10^{19}	-1.0	0	44
$NO + O_2 = N + O + O_2$	5.6×10^{18}	-1.0	151	5,25
$NO^+ + O_2^- = NO + O_2$	3.6×10^{19}	-1.0	0	44
$NO^+ + K = NO + K^+$	4×10^{11}	0.5	0	2
$N_2O + M = N + NO + M$	1×10^{14}	-1.0	115	5
$N_2O + H = N_2 + OH$	3×10^{14}	0.0	16	40
$N_2O + H = NH + NO$	1×10^{11}	0.5	30	2
$N_2O + O_2 = NO + NO_2$	1×10^{13}	0.0	70	5
$NO_2 + H = NO + OH$	5×10^{11}	0.5	5	2
$NO_2 + O = NO + O_2$	2×10^{13}	0.0	1.1	32
$N_2O + O = N + NO_2$	1×10^{13}	0.0	50	5,29

Table 7. Reactions Involving Nitrogen Species (Concluded)

Reaction	A, cc/mole-sec	n	E, kcal/mole	Reference
$2NO = N + O + NO$	1.12×10^{20}	-1.0	151	5,25
$NO + O = N + 2O$	1.12×10^{20}	-1.0	151	5,25
$NO^+ + O^- = NO + O$	3.6×10^{19}	-1.0	0	44
$NO + O_2 = N + O + O_2$	5.6×10^{18}	-1.0	151	5,25
$NO^+ + O_2^- = NO + O_2$	3.6×10^{19}	-1.0	0	44
$NO^+ + K = NO + K^+$	4×10^{11}	0.5	0	2
$N_2O + M = N + NO + M$	1×10^{14}	-1.0	115	5
$N_2O + H = N_2 + OH$	3×10^{14}	0.0	16	40
$N_2O + H = NH + NO$	1×10^{11}	0.5	30	2
$N_2O + O_2 = NO + NO_2$	1×10^{13}	0.0	70	5
$NO_2 + H = NO + OH$	5×10^{11}	0.5	5	2
$NO_2 + O = NO + O_2$	2×10^{13}	0.0	1.1	32
$N_2O + O = N + NO_2$	1×10^{13}	0.0	50	5,29

Table 8. Reactions Involving Potassium Species

Reaction	A, cc/ mole-sec	n	E, kcal/mole	Reference
$K + Cl + M = KCl + M$	3×10^{16}	-0.5	0	2
$K^+ + Cl^- + M = KCl + M$	4×10^{17}	-0.5	0	2
$K + Cl_2 = KCl + Cl$	5×10^{11}	0.5	3	2
$K^+ + e + M = K + M$	5×10^{23}	-1.5	0	2
$K + F + M = KF + M$	3×10^{16}	-0.5	0	2
$K^+ + F^- + M = KF + M$	4×10^{17}	-0.5	0	2
$K + F_2 = KF + F$	5×10^{11}	0.5	2	2
$K^+ + OH^- + M = KOH + M$	4×10^{17}	-0.5	0	2
$K + OH + M = KOH + M$	3×10^{16}	-0.5	0	2
$K + HOH = KOH + H$	1×10^{11}	0.5	6	2
$K + H_3O^+ = K^+ + H + H_2O$	4×10^{11}	0.5	0	2
$KCl + H = HCl + K$	5×10^{11}	0.5	7	2
$KF + H = HF + K$	5×10^{11}	0.5	7	2

Table 9. Reactions Involving Sodium Species

Reaction	A, cc/ mole-sec	n	E, kcal/mole	Reference
$Na + Cl + M = NaCl + M$	3×10^{16}	-0.5	0	2
$Na^+ + Cl^- + M = NaCl + M$	4×10^{17}	-0.5	0	2
$Na + Cl^- = NaCl + e$	5×10^{11}	0.5	0	2
$Na + Cl_2 = NaCl + Cl$	5×10^{11}	0.5	3	2
$Na + ClF = NaF + Cl$	5×10^{11}	0.5	3	2
$Na + ClF = NaCl + F$	5×10^{11}	0.5	3	2
$Na + HCl = NaCl + H$	5×10^{11}	0.5	6	2
$Na^+ + e + M = Na + M$	5×10^{24}	-2.5	0	44
$Na + e = Na^+ + 2e$	2.6×10^{13}	0.5	119	5
$Na^+ + e = Na + h\nu$	1.2×10^{14}	-0.75	0	5
$Na + F + M = NaF + M$	3×10^{16}	-0.5	0	2
$Na^+ + F^- + M = NaF + M$	4×10^{17}	-0.5	0	2
$Na + F_2 = NaF + F$	5×10^{11}	0.5	2	2
$Na^+ + H^- + M = NaH + M$	4×10^{17}	-0.5	0	2
$Na + H + M = NaH + M$	3×10^{16}	-0.5	0	2
$Na + H^- = NaH + e$	5×10^{11}	0.5	0	2
$Na^+ + OH^- + M = NaOH + M$	4×10^{17}	-0.5	0	2
$Na + OH + M = NaOH + M$	3×10^{16}	-0.5	0	2
$Na + OH^- = NaOH + e$	1×10^{11}	0.5	0	2
$Na + HOH = NaOH + H$	1×10^{11}	0.5	6	2

Table 9. Reactions Involving Sodium Species (Continued)

Reaction	A, cc/ mole-sec	n	E, kcal/mole	Reference
$Na + H_3O^+ = Na^+ + H + H_2O$	1×10^{10}	0.5	6	2
$Na + 2N = N_2 + Na^+ + e$	4×10^{15}	0.0	0	42
$Na + N + O = NO + Na^+ + e$	4×10^{15}	0.0	0	42
$Na + NO^+ = Na^+ + NO$	3×10^{13}	-0.5	0	42
$Na^+ + O^- + M = NaO + M$	4×10^{18}	0.0	0	42
$Na + O + M = NaO + M$	3×10^{16}	-0.5	0	2
$Na + O^- = NaO + e$	5×10^{11}	0.5	0	2
$Na^+ + O^- = Na + O$	4×10^{18}	-1.0	0	42
$Na + 2O = O_2 + Na^+ + e$	4×10^{16}	0.0	0	5
$Na + O_2 + M = NaO_2 + M$	4×10^{13}	0.0	0	42
$Na^+ + O_2^- = Na + O_2$	4×10^{18}	-1.0	0	42
$Na^+ + O_2^- = NaO + O$	5×10^{11}	0.5	6	2
$NaCl + O^- + NaO + Cl^-$	5×10^{11}	0.5	2	2
$NaF + H = HF + Na$	1×10^{11}	0.5	6	2
$NaF + O^- = NaO + F^-$	1×10^{11}	0.5	6	2
$NaH + Cl = NaCl + H$	5×10^{11}	0.5	3	2
$NaH + Cl = Na + HCl$	1.8×10^{11}	0.7	10	22
$NaH + F = Na + HF$	1.7×10^{11}	0.7	8	22
$NaH + F = NaF + H$	5×10^{11}	0.5	3	2
$NaH + H = Na + H_2$	1.4×10^{12}	0.7	5	22

Table 9. Reactions Involving Sodium Species (Concluded)

Reaction	A, cc/mole-sec	n	E, kcal/mole	Reference
$NaH + OH = Na + H_2O$	1×10^{11}	0.5	3	2
$NaH + O = Na + OH$	1.3×10^{12}	0.7	1	22
$NaH + O = NaO + H$	5×10^{11}	0.5	3	2
$NaH + NaO = NaOH + Na$	1×10^{11}	0.5	3	2
$NaO + Cl = NaCl + O$	5×10^{11}	0.5	4	2
$NaO + F = NaF + O$	5×10^{11}	0.5	4	2
$NaO + H + M = NaOH + M$	3×10^{16}	-0.5	0	2
$NaO + H^- = Na + OH^-$	5×10^{11}	0.5	4	2
$NaO + H^- = NaOH + e$	5×10^{11}	0.5	0	2
$NaO + HCl = NaOH + Cl$	1×10^{11}	0.5	6	2
$NaO + H_2 = NaOH + H$	1×10^{11}	0.5	6	2
$NaO + OH = NaOH + O$	1×10^{11}	0.5	6	2
$NaO + OH^- = NaOH + O^-$	1×10^{11}	0.5	9	2
$NaO + H_2O = OH + NaOH$	1.3×10^{12}	0.5	0	36
$NaO + O^- = Na + O_2^-$	5×10^{11}	0.5	4	2
$NaO + O = Na + O_2$	5×10^{11}	0.5	6	2
$NaOH + Cl = NaO + HCl$	1.0×10^{11}	0.5	0	36
$NaOH + F = NaO + HF$	1.2×10^{11}	0.5	0	36
$NaOH + H = NaO + H_2$	1.19×10^{12}	0.7	19	22
$NaOH + OH = NaO + H_2O$	1.2×10^{11}	0.5	0	36
$NaOH + O = NaO + OH$	2.6×10^{11}	0.5	0	36

Table 10. Reactions Involving Chlorine Species

Reaction	A, cc/mole-sec	n	E, kcal/mole	Reference
$Cl + Cl^- = Cl_2 + e$	5×10^{11}	0.5	0	2
$Cl + e + M = Cl^- + M$	1×10^{20}	-1.0	0	2
$Cl + H + M = HCl + M$	3×10^{16}	-0.5	0	2
$Cl + H^- = Cl^- + H$	4×10^{11}	0.5	0	2
$Cl + H^- = e + HCl$	5×10^{11}	0.5	0	2
$Cl^- + H = HCl + e$	5×10^{11}	0.5	0	2
$Cl + H_2 = H + HCl$	8.1×10^{13}	0.0	6	31
$Cl + OH^- = Cl^- + OH$	4×10^{11}	0.5	0	2
$Cl^- + H_3O^+ = HCl + H_2O$	1×10^{10}	0.5	6	2
$Cl + O^- = Cl^- + O$	4×10^{11}	0.5	0	2
$Cl + O_2^- = Cl^- + O_2$	5×10^{11}	0.5	0	2
$HCl + F = Cl + HF$	1.9×10^{12}	0.7	0.6	22
$HCl + OH = Cl + H_2O$	1×10^{11}	0.5	6	2
$HCl + O^- = OH + Cl^-$	5×10^{11}	0.5	13	2
$HCl + O = Cl + OH$	2.3×10^{11}	0.6	1	22
$ClF + H = HF + Cl$	5×10^{11}	0.5	3	2
$ClF + H = HCl + F$	5×10^{11}	0.5	3	2

Table 11. Reactions Involving Fluorine Species

Reaction	A, cc/ mole-sec	n	E, kcal/mole	Reference
$F + e + M = F^- + M$	1×10^{20}	-1.0	0	2
$F + OH + HF = O + 2HF$	5×10^{18}	-0.5	6	2,19
$F + H^- = F^- + H$	4×10^{11}	0.5	0	2
$F + 2H = HF + H$	3.5×10^{17}	-0.5	0	2,19
$F + H_2 = H + HF$	7.8×10^{11}	0.7	3	22
$F + H + H_2 = HF + H_2$	7×10^{17}	-0.5	0	2,19
$F + OH^- = F^- + OH$	4×10^{11}	0.5	0	2
$F + OH = O + HF$	2.9×10^{12}	0.7	0.2	22
$F + H_2O = OH + HF$	5.6×10^{11}	0.5	0	36
$F + H_2O = HF + HO$	1×10^{11}	0.5	6	2
$F + H + OH = HF + OH$	5×10^{18}	-0.5	0	2,19
$F^- + H_3O^+ = HF + H_2O$	1×10^{11}	0.5	0	2
$F + H + H_2O = HF + H_2O$	5×10^{18}	-0.5	0	2,19
$F + O^- = F^- + O$	4×10^{11}	0.5	0	2
$F + O_2^- = F^- + O_2$	4×10^{11}	0.5	0	2
$F_2 + M = 2F + M$	7.1×10^{15}	0.0	30	35
$F_2 + H = HF + F$	5.28×10^{12}	0.5	4	23
$HF + M = H + F + M$	5.1×10^{22}	-2.0	134	28
$HF + H = H_2 + F$	1×10^{13}	0.0	35	28
$HF + 2H = H_2 + HF$	1×10^{19}	-0.5	0	2,19
$HF + O^- = HO + F^-$	1×10^{11}	0.5	7	2

Table 12. Reactions Involving Oxygen Species

Reaction	A, cc/mole-sec	n	E, kcal/mole	Reference
$O + O^- + M = O_2^- + M$	4×10^{17}	0.0	0	42
$O + O_2 = 3O$	8.5×10^{19}	-1.0	118	5,33
$O + O_2^- = O_2 + O^-$	4×10^{12}	0.0	0	42
$2O_2 = 2O + O_2$	2×10^{19}	-1.0	118	5
$O_2 + M = 2O + M$	3×10^{18}	-1.0	118	5
$O_2^- + M = O_2 + e + M$	5×10^{13}	0.0	10	2
$O_3 + M = O + O_2 + M$	6×10^{15}	0.0	25	5,34
$O + e + M = O^- + M$	4×10^{15}	0.0	0	21
$O + e + O_2 = O^- + O_2$	4×10^{15}	0.0	0	5
$O + e + N_2 = O^- + N_2$	2×10^{19}	-0.5	0	5
$O + e = O^- + h\nu$	7.2×10^{8}	0.0	0	5
$O_2 + e = O^- + O$	3×10^{15}	-1.0	84	5
$O_2 + e = O_2^- + h\nu$	1×10^{5}	0.0	0	43
$2O_2 + e = O_2^- + O_2$	1.5×10^{21}	-1.0	0	5
$O + H + M = OH + M$	2×10^{18}	-1.0	0	4
$O + H^- + M = OH^- + M$	4×10^{17}	-0.5	0	2
$O^- + H + M = OH^- + M$	6×10^{17}	-0.5	0	2
$O + 2H = OH + H$	3.5×10^{17}	-0.5	0	2,4
$O + H + H_2 = OH + H_2$	7×10^{17}	-0.5	0	2,4
$O + H + OH = 2OH$	5×10^{18}	-0.5	0	2,4
$O + H + H_2O = OH + H_2O$	5×10^{18}	-0.5	0	2,4

Table 12. Reactions Involving Oxygen Species (Continued)

Reaction	A, cc/ mole-sec	n	E, kcal/mole	Reference
$O + H^- = e + OH$	5×10^{11}	0.5	0	2
$O + H^- + O^- + H$	4×10^{11}	0.5	0	2
$O^- + H = OH + e$	5×10^{11}	0.5	0	2
$O^- + H_2 = H + OH^-$	5×10^{11}	0.5	6	2
$O + H_2 = H + OH$	4×10^{13}	0.0	10	37
$O + H_2O = 2OH$	4.2×10^{13}	0.0	18	41
$O^- + OH = O + OH^-$	5×10^{11}	0.5	0	2
$O^- + H_3O^+ = OH + H_2O$	1×10^{10}	0.5	6	2
$O_2 + H + M = O_2H + M$	1×10^{15}	-0.5	0	2,26
$O_2 + H = OH + O$	2×10^{14}	0.0	17	26
$O_2^- + H = OH + O^-$	5×10^{11}	0.5	6	2
$O_2^- + H = O + OH^-$	5×10^{11}	0.5	6	2
$O_2 + H^- = O_2^- + H$	4×10^{11}	0.5	0	2
$O_2 + O_2 = O + O_3$	1×10^{12}	0.0	97	5
$O_2 + H_2 = 2OH$	1×10^{14}	0.0	70	9,23
$O_2^- + OH = OH^- + O_2$	4×10^{11}	0.5	0	2
$OH^- + M = OH + e + M$	5×10^{13}	0.0	10	2
$OH + H + M = H_2O + M$	4.5×10^{21}	-1.5	0	26
$OH + H + H_2O = 2H_2O$	1.8×10^{22}	-1.5	0	
$OH^- + H = H_2O + e$	1×10^{11}	0.5	0	2

Table 12. Reactions Involving Oxygen Species (Concluded)

Reaction	A, cc/ mole-sec	n	E, kcal/mole	Reference
$OH + H^- = e + H_2O$	5×10^{11}	0.5	0	2
$OH + H^- = H + OH^-$	4×10^{11}	0.5	0	2
$OH + 2H = H_2 + OH$	5×10^{18}	-0.5	0	2,19
$OH + H_2 = H + H_2O$	6×10^{11}	0.5	5	38
$OH^- + OH = H_2O + O^-$	1×10^{11}	0.5	9	2
$OH^- + H_3O^+ = 2H_2O$	1×10^{11}	0.5	0	2
$H_2O + H = OH + H_2$	2.9×10^{11}	0.7	18	22
$H_2O + 2H = H_2 + H_2O$	5×10^{18}	-0.5	0	2
$HO_2 + H = H_2 + O_2$	1×10^{11}	0.5	6	2
$H_3O^+ + e = H_2O + H$	3×10^{15}	0.5	0	2,17

Table 13. Reactions Involving Hydrogen Species

Reaction	A, cc/mole-sec	n	E, kcal/mole	Reference
$2H + H_2 = 2H_2$	5×10^{18}	-1.0	0	26
$3H = H_2 + H$	2×10^{19}	-1.0	0	26
$2H + M = H_2 + M$	2×10^{18}	-1.0	0	26
$H + H^- = e + H_2$	5×10^{11}	0.5	0	2
$H + e + M = H^- + M$	1×10^{20}	-1.0	0	2
$H + H + H_2O = H_2 + H_2O$	1.5×10^{19}	-1.0	0	26

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13. ABSTRACT

A compilation of gas-phase rate data for use in nonequilibrium gas composition and propellant performance calculation programs is presented. Reactions are listed with the preexponential factor, temperature exponent, and activation energy for the Arrhenius form of the rate equation. Only undirectional rate data are supplied since reverse rates may be generated from thermochemical data. Explanatory notes on the estimation of the rate data are included with the references.

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