Supplement to *The chemistry of daytime sprite streamers – a model study* (acp-2013-754)

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Chemical reaction scheme

The set of model reactions. The rate coefficients are in units of s^{-1} for unimolecular, $cm^3 s^{-1}$ for two-body, and $cm^6 s^{-1}$ for three-body reactions. T is the gas temperature in Kelvin. M stands for an inert molecule.

No	Reaction	Rate coefficient	Reference
Electron attachment			
EA-1	$e + O_2 + O_2 \rightarrow O_2^- + O_2$	$1.4\times10^{-29}\times(T/300)^{-1}\times\exp(-600/T)$	[15]
EA-2	$e + O_2 + N_2 \rightarrow O_2^- + N_2$	$1.07\times10^{-31}\times(T/300)^{-2}\times\exp(-70/T)$	[15]
EA-3	$e + O + O_2 \rightarrow O^- + O_2$	10^{-31}	[9]
EA-4	$e + O + O_2 \rightarrow O_2^- + O$	10^{-31}	[9]
EA-5	$e + O_3 \rightarrow O_2^- + O$	10^{-9}	[9]
EA-6	$e + O_3 \rightarrow O^- + O_2$	10^{-11}	[9]
EA-7	$e + O_3 + O_2 \rightarrow O_3^- + O_2$	10^{-31}	[3]
EA-8	$e + NO + M \rightarrow NO^- + M$	10^{-30}	[9]
EA-9	$e + NO_2 \rightarrow NO_2^-$	3×10^{-11}	[9]
EA-10	$e + NO_2 \rightarrow O^- + NO$	10^{-11}	[9]
EA-11	$e + H_2O + O_2 \rightarrow O_2^- + H_2O$	1.4×10^{-29}	[3]
Electron detachment			
ED-1	$O_2^- + N_2 \rightarrow e + O_2 + N_2$	$1.9\times10^{-12}\times(T/300)^{0.5}\times\exp(-4990/T)$	[9]
ED-2	$O_2^- + O_2 \rightarrow e + O_2 + O_2$	$2.7\times10^{-10}\times(T/300)^{0.5}\times\exp(-5990/T)$	[9]
ED-3	$O_2^- + O_2(a) \rightarrow e + O_2 + O_2$	2×10^{-10}	[9]
ED-4	$O_2^- + O_2(b) \rightarrow e + O_2 + O_2$	3.6×10^{-10}	[9]
ED-5	$O_2^- + N_2(A) \rightarrow e + O_2 + N_2$	2.1×10^{-9}	[9]
ED-6	$O_2^- + N_2(B) \rightarrow e + O_2 + N_2$	2.5×10^{-9}	[9]
ED-7	$O_2^- + O \rightarrow e + O_3$	1.5×10^{-10}	[9]
ED-8	$O_2^- + N \rightarrow e + NO_2$	5×10^{-10}	[9]
ED-9	$O_2^- + H_2O \rightarrow e + H_2O + O_2$	$5\times10^{-9}\times\exp(-5000/T)$	[3]
ED-10	$O^- + O_2(a) \rightarrow e + O_3$	3×10^{-10}	[9]
ED-11	$O^- + O_2(b) \rightarrow e + O + O_2$	6.9×10^{-10}	[9]
ED-12	$O^- + N_2(A) \rightarrow e + O + N_2$	2.2×10^{-9}	[9]
ED-13	$O^- + N_2(B) \rightarrow e + O + N_2$	1.9×10^{-9}	[9]
ED-14	$O^- + N_2 \rightarrow e + N_2O$	10^{-12}	[3]
ED-15	$O^- + H_2 \rightarrow e + H_2O$	7×10^{-10}	[3]
ED-16	$O^- + O \rightarrow e + O_2$	5×10^{-10}	[9]
ED-17	$O^- + N \rightarrow e + NO$	2.6×10^{-10}	[9]
ED-18	$O^- + O_2 \rightarrow e + O_3$	5×10^{-15}	[9]
ED-19	$O^- + NO \rightarrow e + NO_2$	2.6×10^{-10}	[9]

ED-20	$O^- + O_3 \rightarrow e + O_2 + O_2$	$5\times10^{-10}\times(T/300)^{0.5}$	[15]
ED-21	$O_3^- + O \rightarrow e + O_2 + O_2$	3×10^{-10}	[9]
ED-22	$O_3^- + O_3 \rightarrow e + 3O_2$	10^{-10}	[3]
ED-23	$NO^- + N_2O \rightarrow e + NO + N_2O$	5.1×10^{-12}	[3]
ED-24	$NO^- + NO \rightarrow e + NO + NO$	5×10^{-12}	[3]
ED-25	$NO^- + CO_2 \rightarrow e + NO + CO_2$	8.3×10^{-12}	[3]
ED-26	$NO_2^- + O \rightarrow e + NO_3$	10^{-12}	[9]
ED-27	$OH^- + O \rightarrow e + HO_2$	$4\times10^{-10}\times(T/300)^{0.5}$	[15]
ED-28	$Cl^- + H \rightarrow e + HCl$	$9.3\times10^{-10}\times(T/300)^{0.5}$	[15]
Associative and Penning ionisation			
AI-1	$N_2(a'^1) + N_2(A) \rightarrow e + N_4^+$	1.5×10^{-11}	[3]
AI-2	$N_2(a'^1) + N_2(a'^1) \rightarrow e + N_4^+$	10^{-11}	[3]
AI-3	$N_2(a^1) + N_2(a^1) \rightarrow e + N_2^+$	2×10^{-10}	[3]
AI-4	$N(^2P) + N(^2P) \rightarrow e + N_2^+$	10^{-11}	[12]
AI-5	$N(^2P) + O \rightarrow e + NO^+$	10^{-11}	[12]
AI-6	$N(^2P) + N(^2D) \rightarrow e + N_2^+$	10^{-12}	[9]
Positive ion chemistry			
P-1	$N_2^+ + N + N_2 \rightarrow N_3^+ + N_2$	$9\times10^{-30}\times\exp(400/T)$	[9]
P-2	$N_2^+ + O_2 \rightarrow O_2^+ + N_2$	$6\times10^{-11}\times(T/300)^{-0.5}$	[9]
P-3	$N_2^+ + O \rightarrow NO^+ + N$	$1.3\times10^{-10}\times(T/300)^{-0.5}$	[9]
P-4	$N_2^+ + O \rightarrow O^+ + N_2$	$10^{-11}\times(T/300)^{-0.2}$	[9]
P-5	$N_2^+ + O_3 \rightarrow O_2^+ + O + N_2$	10^{-10}	[9]
P-6	$N_2^+ + N_2O \rightarrow N_2O^+ + N_2$	5×10^{-10}	[9]
P-7	$N_2^+ + N_2O \rightarrow NO^+ + N + N_2$	4×10^{-10}	[9]
P-8	$N_2^+ + NO \rightarrow NO^+ + N_2$	3.3×10^{-10}	[9]
P-9	$N_2^+ + N_2 + N_2 \rightarrow N_4^+ + N_2$	$5.2\times10^{-29}\times(T/300)^{-2.2}$	[3]
P-10	$N_2^+ + N_2(A) \rightarrow N_3^+ + N$	3×10^{-10}	[9]
P-11	$N_2^+ + N \rightarrow N^+ + N_2$	$2.4\times10^{-15}\times T$	[9]
P-12	$N_2^+ + O_2 \rightarrow NO_2^+ + N_2$	4.4×10^{-11}	[9]
P-13	$N_3^+ + O_2 \rightarrow O_2^+ + N + N_2$	2.3×10^{-11}	[9]
P-14	$N_3^+ + NO \rightarrow N_2O^+ + N_2$	$7\times10^{-11}\times(T/300)^{0.5}$	[15]
P-15	$N_3^+ + N_2(A) \rightarrow N_3^+ + N_2$	3×10^{-10}	[3]
P-16	$N_3^+ + N \rightarrow N_2^+ + N_2$	6.6×10^{-11}	[9]
P-17	$N_3^+ + NO \rightarrow NO^+ + N + N_2$	7×10^{-11}	[9]
P-18	$N_3^+ + NO \rightarrow N_2O^+ + N_2$	7×10^{-11}	[9]
P-19	$N_3^+ + O_2 \rightarrow O_2^+ + N + N_2$	2.3×10^{-11}	[3]
P-20	$N_4^+ + N_2 \rightarrow N_2^+ + N_2 + N_2$	$2.1\times10^{-16}\times(T/300)^{0.5}$	[15]
P-21	$N_4^+ + O_2 \rightarrow O_2^+ + N_2 + N_2$	2.5×10^{-10}	[15]
P-22	$N_4^+ + O \rightarrow O^+ + N_2 + N_2$	2.5×10^{-10}	[9]
P-23	$N_4^+ + N \rightarrow N^+ + N_2 + N_2$	10^{-11}	[9]
P-24	$N_4^+ + NO \rightarrow NO^+ + N_2 + N_2$	4×10^{-10}	[9]
P-25	$N^+ + N_2 + N_2 \rightarrow N_3^+ + N_2$	$9\times10^{-30}\times\exp(400/T)$	[9]
P-26	$N^+ + N + M \rightarrow N_2^+ + M$	10^{-29}	[9]
P-27	$N^+ + O + M \rightarrow NO^+ + M$	10^{-29}	[9]
P-28	$N^+ + O \rightarrow O^+ + N$	10^{-12}	[9]
P-29	$N^+ + O_3 \rightarrow NO^+ + O_2$	5×10^{-10}	[9]
P-30	$N^+ + O_2 \rightarrow O_2^+ + N$	$2\times10^{-10}\times(T/300)^{0.5}$	[15]
P-31	$N^+ + O_2 \rightarrow O_2^+ + N(^2D)$	$8.4\times10^{-11}\times(T/300)^{0.5}$	[15]
P-32	$N^+ + O_2 \rightarrow NO^+ + O$	$5\times10^{-11}\times(T/300)^{0.5}$	[15]
P-33	$N^+ + O_2 \rightarrow NO^+ + O(^1D)$	$2\times10^{-10}\times(T/300)^{0.5}$	[15]
P-34	$N^+ + O_2 \rightarrow O^+ + NO$	2.8×10^{-11}	[9]
P-35	$N^+ + NO \rightarrow NO^+ + N$	8×10^{-10}	[9]
P-36	$N^+ + NO \rightarrow N_2^+ + O$	3×10^{-12}	[9]
P-37	$N^+ + NO \rightarrow O^+ + N_2$	10^{-12}	[9]

P-38	$N^+ + N_2O \rightarrow NO^+ + N_2$	5.5×10^{-10}	[9]
P-39	$O_2^+ + O_2 + O_2 \rightarrow O_4^+ + O_2$	$2.4\times10^{-30}\times(T/300)^{-3.2}$	[9]
P-40	$O_2^+ + N_2 + N_2 \rightarrow N_2O_2^+ + N_2$	$9\times10^{-31}\times(T/300)^{-2}$	[9]
P-41	$O_2^+ + N_2 \rightarrow NO^+ + NO$	$4\times10^{-21}\times(T/300)^{-2}$	[16]
P-42	$O_2^+ + N \rightarrow NO^+ + O$	1.2×10^{-10}	[9]
P-43	$O_2^+ + NO \rightarrow NO^+ + O_2$	4.4×10^{-10}	[9]
P-44	$O_2^+ + NO_2 \rightarrow NO_2^+ + O_2$	6.6×10^{-10}	[9]
P-45	$O_2^+ + NO_2 \rightarrow NO^+ + O_3$	10^{-11}	[9]
P-46	$O_2^+ + N_2O_5 \rightarrow NO_2^+ + NO_3 + O_2$	8.8×10^{-10}	[9]
P-47	$O_4^+ + O_2 \rightarrow O_2^+ + O_2 + O_2$	$3.3\times10^{-6}\times(T/300)^{-4}\times\exp(-5030/T)$	[9]
P-48	$O_4^+ + O_2(a) \rightarrow O_2^+ + O_2 + O_2$	10^{-10}	[9]
P-49	$O_4^+ + O_2(b) \rightarrow O_2^+ + O_2 + O_2$	10^{-10}	[9]
P-50	$O_4^+ + O \rightarrow O_2^+ + O_3$	3×10^{-10}	[9]
P-51	$O_4^+ + NO \rightarrow NO^+ + O_2 + O_2$	10^{-10}	[9]
P-52	$O_4^+ + N_2 \rightarrow N_2O_2^+ + O_2$	$4.61\times10^{-12}\times(T/300)^{2.5}\times\exp(-2650/T)$	[9]
P-53	$N_2O_2^+ + N_2 \rightarrow O_2^+ + 2N_2$	$1.1\times10^{-6}\times(T/300)^{-5.3}\times\exp(-2357/T)$	[9]
P-54	$N_2O_2^+ + O_2 \rightarrow O_4^+ + N_2$	10^{-9}	[9]
P-55	$N_2O_2^+ + H_2O \rightarrow O_2^+(H_2O) + N_2$	4×10^{-9}	[4]
P-56	$O^+ + O + M \rightarrow O_2^+ + M$	10^{-29}	[9]
P-57	$O^+ + N + M \rightarrow NO^+ + M$	10^{-29}	[9]
P-58	$O^+ + O_2 \rightarrow O_2^+ + O$	$2\times10^{-11}\times(T/300)^{-0.4}$	[15]
P-59	$O^+ + N_2 \rightarrow NO^+ + N$	$1.2\times10^{-12}\times(T/300)^{-1}$	[15]
P-60	$O^+ + N_2 + M \rightarrow NO^+ + N + M$	$6\times10^{-29}\times(T/300)^{-2}$	[9]
P-61	$O^+ + NO_2 \rightarrow NO_2^+ + O$	1.6×10^{-9}	[9]
P-62	$O^+ + NO \rightarrow NO^+ + O$	2.4×10^{-11}	[9]
P-63	$O^+ + NO \rightarrow O_2^+ + N$	3×10^{-12}	[9]
P-64	$O^+ + N(^2D) \rightarrow N^+ + O$	1.3×10^{-10}	[9]
P-65	$O^+ + N_2O \rightarrow N_2O^+ + O$	4×10^{-10}	[9]
P-66	$O^+ + N_2O \rightarrow NO^+ + NO$	2.3×10^{-10}	[9]
P-67	$O^+ + N_2O \rightarrow O_2^+ + N_2$	2×10^{-11}	[9]
P-68	$O^+ + O_3 \rightarrow O_2^+ + O_2$	10^{-10}	[9]
P-69	$NO_2^+ + NO \rightarrow NO^+ + NO_2$	2.9×10^{-10}	[9]
P-70	$N_2O^+ + NO \rightarrow NO^+ + N_2O$	2.9×10^{-10}	[9]
P-71	$NO^+ + N_2 + N_2 \rightarrow NO^+(N_2) + N_2$	$2\times10^{-31}\times(T/300)^{-4.4}$	[9]
P-72	$NO^+ + O_2 + N_2 \rightarrow NO^+(O_2) + N_2$	3×10^{-31}	[9]
P-73	$NO^+ + O_2 + O_2 \rightarrow NO^+(O_2) + O_2$	9×10^{-32}	[9]
P-74	$NO^+ + O_3 \rightarrow NO_2^+ + O_2$	10^{-15}	[9]
P-75	$NO^+ + N_2O_5 \rightarrow NO_2^+ + 2NO_2$	5.9×10^{-10}	[9]
P-76	$O^+ + H_2 \rightarrow OH^+ + H$	1.62×10^{-9}	[3]
P-77	$O^+ + H_2O \rightarrow H_2O^+ + O$	2.6×10^{-9}	[3]
P-78	$H_2O^+ + O_2 \rightarrow O_2^+ + H_2O$	3.3×10^{-10}	[3]
P-79	$H_2O^+ + NO_2 \rightarrow NO_2^+ + H_2O$	1.2×10^{-9}	[3]
P-80	$H_2O^+ + NO \rightarrow NO^+ + H_2O$	4.6×10^{-9}	[3]
P-81	$OH^+ + O_2 \rightarrow O_2^+ + OH$	3.8×10^{-10}	[3]
P-82	$N_4^+ + H_2O \rightarrow H_2O^+ + 2N_2$	3×10^{-9}	[3]
P-83	$N_2^+ + H_2O \rightarrow H_2O^+ + N_2$	2.4×10^{-9}	[3]
P-84	$N^+ + H_2O \rightarrow H_2O^+ + N$	2.7×10^{-9}	[6]
P-85	$H_2O^+ + H_2O \rightarrow H^+(H_2O) + OH$	1.85×10^{-9}	[3]
P-86	$H_2O^+ + H_2 \rightarrow H^+(H_2O) + H$	7.6×10^{-10}	[6]
P-87	$H^+(H_2O) + H_2O + M \rightarrow H^+(H_2O)_2 + M$	$4.6\times10^{-27}\times(T/300)^{-4}$	[6]
P-88	$H^+(H_2O)_2 + H_2O + M \rightarrow H^+(H_2O)_3 + M$	$8.6\times10^{-27}\times(T/300)^{-7.5}$	[6]
P-89	$H^+(H_2O)_3 + H_2O + M \rightarrow H^+(H_2O)_4 + M$	$3.6\times10^{-27}\times(T/300)^{-8.1}$	[6]
P-90	$H^+(H_2O)_4 + H_2O + M \rightarrow H^+(H_2O)_5$	$4.6\times10^{-28}\times(T/300)^{-14.0}$	[6]
P-91	$H^+(H_2O)_5 + H_2O + M \rightarrow H^+(H_2O)_6$	$5.8\times10^{-29}\times(T/300)^{-15.3}$	[6]

P-92	$H^+(H_2O)_6 + H_2O + M \rightarrow H^+(H_2O)_7$	$5.74\times10^{-29}\times(T/300)^{-15.3}$	[6]
P-93	$H^+(H_2O)_2 + M \rightarrow H^+(H_2O) + H_2O + M$	$2.5\times10^{-2}\times(T/300)^{-5}\times\exp(-15900/T)$	[6]
P-94	$H^+(H_2O)_3 + M \rightarrow H^+(H_2O)_2 + H_2O + M$	$1.2\times10^{-2}\times(T/300)^{-8.5}\times\exp(-9800/T)$	[6]
P-95	$H^+(H_2O)_4 + M \rightarrow H^+(H_2O)_3 + H_2O + M$	$1.5\times10^{-1}\times(T/300)^{-9.1}\times\exp(-9000/T)$	[6]
P-96	$H^+(H_2O)_5 + M \rightarrow H^+(H_2O)_4 + H_2O + M$	$1.7\times10^{-3}\times(T/300)^{-15}\times\exp(-6400/T)$	[6]
P-97	$H^+(H_2O)_6 + M \rightarrow H^+(H_2O)_5 + H_2O + M$	$4\times10^{-3}\times(T/300)^{-16.3}\times\exp(-5800/T)$	[6]
P-98	$H^+(H_2O)_7 + M \rightarrow H^+(H_2O)_6 + H_2O + M$	$7.17\times10^{-4}\times(T/300)^{-16.3}\times\exp(-5390/T)$	[6]
P-99	$O_4^+ + H_2O \rightarrow O_2^+(H_2O) + O_2$	$1.5\times10^{-9}\times(T/300)^{0.5}$	[15]
P-100	$O_2^+(H_2O) + H_2O \rightarrow H^+(H_2O) + OH + O_2$	$2\times10^{-10}\times(T/300)^{0.5}$	[15]
P-101	$O_2^+(H_2O) + H_2O \rightarrow H^+(H_2O)(OH) + O_2$	$10^{-9}\times(T/300)^{0.5}$	[15]
P-102	$H^+(H_2O)(OH) + H_2O \rightarrow H^+(H_2O)_2 + OH$	$1.4\times10^{-9}\times(T/300)^{0.5}$	[15]
P-103	$O_2^+ + H_2O + N_2 \rightarrow O_2^+(H_2O) + N_2$	2.5×10^{-28}	[6]
P-104	$O_2^+ + H_2O + O_2 \rightarrow O_2^+(H_2O) + O_2$	2.6×10^{-28}	[6]
P-105	$NO^+ + H_2O + M \rightarrow NO^+(H_2O) + M$	$1.8\times10^{-28}\times(T/300)^{-4.7}$	[15]
P-106	$NO^+(H_2O) + H_2O + M \rightarrow NO^+(H_2O)_2 + M$	$10^{-27}\times(T/300)^{-4.7}$	[15]
P-107	$NO^+(H_2O)_2 + H_2O + M \rightarrow NO^+(H_2O)_3 + M$	$10^{-27}\times(T/300)^{-4.7}$	[15]
P-108	$NO^+(H_2O)_3 + H_2O \rightarrow H^+(H_2O)_3 + HNO_2$	7×10^{-11}	[6]
P-109	$NO^+ + CO_2 + M \rightarrow NO^+(CO_2) + M$	$7\times10^{-30}\times(T/300)^{-3}$	[15]
P-110	$NO^+(CO_2) + H_2O \rightarrow NO^+(H_2O) + CO_2$	$10^{-9}\times(T/300)^{0.5}$	[15]
P-111	$NO^+(CO_2) + M \rightarrow NO^+ + CO_2 + M$	$6.2\times10^{-7}\times(T/300)^{-5}\times\exp(-4590/T)$	[6]
P-112	$NO^+(H_2O) + CO_2 + M \rightarrow NO^+(H_2O)(CO_2) + M$	$7\times10^{-30}\times(T/300)^{-3}$	[15]
P-113	$NO^+(H_2O)(CO_2) + H_2O \rightarrow NO^+(H_2O)_2 + CO_2$	$10^{-9}\times(T/300)^{0.5}$	[15]
P-114	$NO^+(H_2O)_2 + CO_2 + M \rightarrow NO^+(H_2O)_2(CO_2) + M$	$7\times10^{-30}\times(T/300)^{-3}$	[15]
P-115	$NO^+(H_2O)_2(CO_2) + H_2O \rightarrow NO^+(H_2O)_3 + CO_2$	$10^{-9}\times(T/300)^{0.5}$	[15]
P-116	$NO^+(H_2O)_2(CO_2) + M \rightarrow NO^+(H_2O)_2 + CO_2 + M$	$3.8\times10^{-6}\times(T/300)^{-5}\times\exp(-3335/T)$	[6]
P-117	$NO^+(H_2O)(CO_2) + M \rightarrow NO^+(H_2O) + CO_2 + M$	$3.8\times10^{-6}\times(T/300)^{-5}\times\exp(-4025/T)$	[6]
P-118	$NO^+(H_2O)_2 + N_2 + M \rightarrow NO^+(H_2O)_2(N_2) + M$	$2\times10^{-31}\times(T/300)^{-4.4}$	[15]
P-119	$NO^+(H_2O)(N_2) + CO_2 \rightarrow NO^+(H_2O)(CO_2) + N_2$	$10^{-9}\times(T/300)^{0.5}$	[15]
P-120	$NO^+(H_2O)_2(N_2) + CO_2 \rightarrow NO^+(H_2O)_2(CO_2) + N_2$	$10^{-9}\times(T/300)^{0.5}$	[15]
P-121	$NO^+(H_2O) + N_2 + M \rightarrow NO^+(H_2O)(N_2) + M$	$2\times10^{-31}\times(T/300)^{-4.4}$	[6]
P-122	$NO^+(H_2O)(N_2) + M \rightarrow NO^+(H_2O) + N_2 + M$	$6.3\times10^{-8}\times(T/300)^{-5.4}\times\exp(-2150/T)$	[6]
P-123	$NO^+(H_2O)_2(N_2) + M \rightarrow NO^+(H_2O)_2 + N_2 + M$	$6.3\times10^{-8}\times(T/300)^{-5.4}\times\exp(-1800/T)$	[6]
P-124	$NO^+(N_2) + CO_2 \rightarrow NO^+(CO_2) + N_2$	7.99×10^{-10}	[6]
P-125	$NO^+(N_2) + H_2O \rightarrow NO^+(H_2O) + N_2$	$2.35\times10^{-9}\times(T/300)^{-0.5} + 2.41\times10^{-10}$	[6]
P-126	$NO^+(N_2) + M \rightarrow NO^+ + N_2 + M$	$1.5\times10^{-8}\times(T/300)^{-5.3}\times\exp(-2093/T)$	[6]
P-127	$NO^+(N_2) + O_2 \rightarrow NO^+ + N_2$	10^{-9}	[16]
P-128	$NO^+(O_2) + O_2 \rightarrow NO^+ + O_2$	10^{-9}	[16]
P-129	$H^+(H_2O) + CO_2 + M \rightarrow H^+(H_2O)(CO_2) + M$	$8.5\times10^{-28}\times(T/300)^{-4}$	[6]
P-130	$H^+(H_2O) + N_2 + M \rightarrow H^+(H_2O)(N_2) + M$	$3.5\times10^{-31}\times(T/300)^{-4}$	[6]
P-131	$H^+(H_2O)(CO_2) + H_2O \rightarrow H^+(H_2O)_2 + CO_2$	$2.33\times10^{-9}\times(T/300)^{-0.5} + 2.39\times10^{-10}$	[6]
P-132	$H^+(H_2O)(CO_2) + M \rightarrow H^+(H_2O) + CO_2 + M$	$5.5\times10^{-3}\times(T/300)^{-5}\times\exp(-7700/T)$	[6]
P-133	$H^+(H_2O)(N_2) + CO_2 \rightarrow H^+(H_2O)(CO_2) + N_2$	8.38×10^{-10}	[6]
P-134	$H^+(H_2O)(N_2) + H_2O \rightarrow H^+(H_2O)_2 + N_2$	2.6×10^{-9}	[6]
P-135	$H^+(H_2O)(N_2) + M \rightarrow H^+(H_2O) + N_2 + M$	$10^{-8}\times(T/300)^{-5.4}\times\exp(-2800/T)$	[6]
P-136	$H^+(H_2O)_2 + CO_2 + M \rightarrow H^+(H_2O)_2(CO_2) + M$	$8.5\times10^{-28}\times(T/300)^{-4}$	[6]
P-137	$H^+(H_2O)_2 + N_2 + M \rightarrow H^+(H_2O)_2(N_2) + M$	$3.5\times10^{-31}\times(T/300)^{-4}$	[6]
P-138	$H^+(H_2O)_2(CO_2) + H_2O \rightarrow H^+(H_2O)_3 + CO_2$	$2.27\times10^{-9}\times(T/300)^{-0.5} + 2.33\times10^{-10}$	[6]
P-139	$H^+(H_2O)_2(CO_2) + M \rightarrow H^+(H_2O)_2 + CO_2 + M$	$10^{-3}\times(T/300)^{-5}\times\exp(-6200/T)$	[6]
P-140	$H^+(H_2O)_2(N_2) + CO_2 \rightarrow H^+(H_2O)_2(CO_2) + N_2$	7.8×10^{-10}	[6]
P-141	$H^+(H_2O)_2(N_2) + M \rightarrow H^+(H_2O)_2 + N_2 + M$	$1.2\times10^{-8}\times(T/300)^{-5.4}\times\exp(-2700/T)$	[6]
Negative ion chemistry			
N-1	$e + O_3 \rightarrow e + O + O_2$	10^{-8}	[3]
N-2	$O^- + O_3 \rightarrow O_3^- + O$	5.3×10^{-10}	[9]
N-3	$O^- + O_2 + M \rightarrow O_3^- + M$	$1.1\times10^{-30}\times(T/300)^{-1}$	[9]
N-4	$O^- + O_2(a) \rightarrow O_2^- + O$	10^{-10}	[9]
N-5	$O_2^- + O \rightarrow O^- + O_2$	3.3×10^{-10}	[9]

N-6	$O_2^- + O_2 + M \rightarrow O_4^- + M$	$3.5\times10^{-31}\times(T/300)^{-1}$	[9]
N-7	$O_2^- + O_3 \rightarrow O_3^- + O_2$	4×10^{-10}	[9]
N-8	$O_3^- + O \rightarrow O_2^- + O_2$	3.2×10^{-10}	[9]
N-9	$O_4^- + M \rightarrow O_2^- + O_2 + M$	$10^{-10}\times\exp(-1044/T)$	[9]
N-10	$O_4^- + O \rightarrow O_3^- + O_2$	4×10^{-10}	[9]
N-11	$O_4^- + O \rightarrow O^- + 2O_2$	3×10^{-10}	[9]
N-12	$O_4^- + O_2(a) \rightarrow O_2^- + 2O_2$	10^{-10}	[9]
N-13	$O_4^- + O_2(b) \rightarrow O_2^- + 2O_2$	10^{-10}	[9]
N-14	$O^- + CO_2 + M \rightarrow CO_3^- + M$	$3.1\times10^{-28}\times(T/300)^{0.5}$	[15]
N-15	$O_2^- + CO_2 + M \rightarrow CO_4^- + M$	4.7×10^{-29}	[6]
N-16	$O_3^- + CO_2 \rightarrow CO_3^- + O_2$	$5.5\times10^{-10}\times(T/300)^{0.5}$	[15]
N-17	$O_4^- + CO_2 \rightarrow CO_4^- + O_2$	$4.3\times10^{-10}\times(T/300)^{0.5}$	[15]
N-18	$O^- + NO + M \rightarrow NO_2^- + M$	10^{-29}	[9]
N-19	$O^- + NO_2 \rightarrow NO_2^- + O$	1.2×10^{-9}	[9]
N-20	$O^- + N_2O \rightarrow NO^- + NO$	2×10^{-10}	[9]
N-21	$O_2^- + NO_2 \rightarrow NO_2^- + O_2$	8×10^{-10}	[9]
N-22	$O_2^- + NO_3 \rightarrow NO_3^- + O_2$	5×10^{-10}	[9]
N-23	$O_3^- + NO \rightarrow NO_2^- + O_2$	2.6×10^{-12}	[9]
N-24	$O_3^- + NO \rightarrow NO_3^- + O$	10^{-11}	[9]
N-25	$O_3^- + NO_2 \rightarrow NO_2^- + O_3$	7×10^{-10}	[9]
N-26	$O_3^- + NO_2 \rightarrow NO_3^- + O_2$	2×10^{-11}	[9]
N-27	$O_3^- + NO_3 \rightarrow NO_3^- + O_3$	5×10^{-10}	[9]
N-28	$NO^- + O_2 \rightarrow O_2^- + NO$	5×10^{-10}	[9]
N-29	$NO^- + NO_2 \rightarrow NO_2^- + NO$	7.4×10^{-16}	[9]
N-30	$NO^- + N_2O \rightarrow NO_2^- + N_2$	2.8×10^{-14}	[9]
N-31	$NO_2^- + O_3 \rightarrow NO_3^- + O_2$	1.8×10^{-11}	[9]
N-32	$NO_2^- + NO_2 \rightarrow NO_3^- + NO$	4×10^{-12}	[9]
N-33	$NO_2^- + NO_3 \rightarrow NO_3^- + NO_2$	5×10^{-10}	[9]
N-34	$NO_3^- + NO \rightarrow NO_2^- + NO_2$	3×10^{-15}	[9]
N-35	$NO_2^- + N_2O_5 \rightarrow NO_3^- + NO_3 + NO$	7×10^{-10}	[9]
N-36	$CO_3^- + O \rightarrow O_2^- + CO_2$	$1.1\times10^{-10}\times(T/300)^{0.5}$	[15]
N-37	$CO_3^- + NO \rightarrow NO_2^- + CO_2$	$1.1\times10^{-11}\times(T/300)^{0.5}$	[15]
N-38	$CO_3^- + NO_2 \rightarrow NO_3^- + CO_2$	$2\times10^{-10}\times(T/300)^{0.5}$	[15]
N-39	$CO_4^- + O \rightarrow CO_3^- + O_2$	$1.4\times10^{-10}\times(T/300)^{0.5}$	[15]
N-40	$CO_4^- + O_3 \rightarrow O_3^- + CO_2 + O_2$	$1.3\times10^{-10}\times(T/300)^{0.5}$	[15]
N-41	$CO_4^- + NO \rightarrow NO_3^- + CO_2$	4.8×10^{-11}	[3]
N-42	$O^- + H_2O + M \rightarrow O^-(H_2O) + M$	1.3×10^{-28}	[3]
N-43	$O_2^- + H_2O + M \rightarrow O_2^-(H_2O) + M$	2.2×10^{-28}	[3]
N-44	$O_3^- + H_2O + M \rightarrow O_3^-(H_2O) + M$	2.7×10^{-28}	[3]
N-45	$O^-(H_2O) + O_2 \rightarrow O_3^- + H_2O$	6.2×10^{-11}	[3]
N-46	$O_2^- + HNO_3 \rightarrow NO_3^- + HO_2$	2.9×10^{-9}	[3]
N-47	$O_2^-(H_2O) + NO_2 \rightarrow NO_2^- + H_2O + O_2$	9×10^{-10}	[3]
N-48	$O_2^-(H_2O) + NO \rightarrow NO_3^- + H_2O$	3.1×10^{-10}	[3]
N-49	$O_2^-(H_2O) + O_3 \rightarrow O_3^- + H_2O + O_2$	8×10^{-10}	[3]
N-50	$O_3^-(H_2O) + CO_2 \rightarrow CO_3^- + H_2O + O_2$	1.8×10^{-10}	[3]
N-51	$O_2^-(H_2O) + CO_2 \rightarrow CO_4^- + H_2O$	5.8×10^{-10}	[3]
N-52	$CO_3^- + HNO_3 \rightarrow NO_3^- + OH + CO_2$	3.51×10^{-10}	[3]
N-53	$NO_2^- + H \rightarrow OH^- + NO$	$3\times10^{-10}\times(T/300)^{0.5}$	[15]
N-54	$OH^- + O_3 \rightarrow O_3^- + OH$	$9\times10^{-10}\times(T/300)^{0.5}$	[15]
N-55	$OH^- + CO_2 + M \rightarrow HCO_3^- + M$	$7.6\times10^{-28}\times(T/300)^{0.5}$	[15]
N-56	$O^- + HCl \rightarrow Cl^- + OH$	$2\times10^{-9}\times(T/300)^{0.5}$	[15]
N-57	$O_2^- + HCl \rightarrow Cl^- + HO_2$	$1.6\times10^{-9}\times(T/300)^{0.5}$	[15]
N-58	$CO_3^- + H \rightarrow OH^- + CO_2$	1.7×10^{-10}	[6]

N-59	$OH^- + HCl \rightarrow Cl^- + H_2O$	10^{-10}	[8]
N-60	$NO_2^- + HCl \rightarrow Cl^- + HNO_2$	1.4×10^{-9}	[8]
N-61	$NO_3^- + HCl \rightarrow Cl^- + HNO_3$	10^{-12}	[8]
N-62	$CO_3^- + HCl \rightarrow Cl^- + OH + CO_2$	3×10^{-11}	[7]
N-63	$Cl^- + NO_2 \rightarrow NO_2^- + Cl$	6×10^{-12}	[7]
N-64	$Cl^- + HNO_3 \rightarrow NO_3^- + HCl$	1.6×10^{-9}	[8]
N-65	$Cl^- + O_3 \rightarrow ClO^- + O_2$	5×10^{-13}	[8]
N-66	$ClO^- + O_3 \rightarrow Cl^- + O_2 + O_2$	6×10^{-11}	[8]
N-67	$ClO^- + O_3 \rightarrow O_3^- + ClO + O_2$	10^{-11}	[8]
N-68	$ClO^- + NO \rightarrow NO_2^- + Cl$	2.9×10^{-11}	[8]
N-69	$Cl^- + H_2O + M \rightarrow Cl^-(H_2O) + M$	$2\times10^{-29}\times(T/300)^{-2}$	[8]
N-70	$Cl^-(H_2O) + M \rightarrow Cl^- + H_2O + M$	$9.2\times10^{-6}\times(T/300)^{-3}\times\exp(-7450/T)$	[8]
N-71	$Cl^-(H_2O) + H \rightarrow e + HCl + H_2O$	8×10^{-11}	[8]
N-72	$Cl^- + CO_2 + M \rightarrow Cl^-(CO_2) + M$	$6\times10^{-29}\times(T/300)^{-2}$	[8]
N-73	$Cl^-(CO_2) + M \rightarrow Cl^- + CO_2 + M$	$2.6\times10^{-5}\times(T/300)^{-3}\times\exp(-4000/T)$	[8]
N-74	$Cl^- + HCl + M \rightarrow Cl^-(HCl) + M$	10^{-27}	[6]
N-75	$Cl^-(H_2O) + HCl \rightarrow Cl^-(HCl) + H_2O$	1.30×10^{-9}	[6]
N-76	$Cl^-(HCl) + M \rightarrow Cl^- + HCl + M$	$3.33\times10^{-3}\times(300/T)\times\exp(-11926/T)$	[6]
Electron-ion recombination			
EI-1	$e + N_2^+ \rightarrow N + N$	$2.8\times10^{-7}\times(T/300)^{-0.5}$	[9]
EI-2	$e + N_2^+ \rightarrow N + N(^2D)$	$2\times10^{-7}\times(T/300)^{-0.5}$	[9]
EI-3	$e + O_2^+ \rightarrow O + O$	$3.84\times10^{-8}\times(T/300)^{-0.7}$	[15]
EI-4	$e + O_2^+ \rightarrow O + O(^1D)$	$1.13\times10^{-7}\times(T/300)^{-0.7}$	[15]
EI-5	$e + O_2^+ \rightarrow O(^1D) + O(^1D)$	$8.88\times10^{-8}\times(T/300)^{-0.7}$	[15]
EI-6	$e + O_2^+ + M \rightarrow O_2 + M$	$6\times10^{-27}\times(T/300)^{-1.5}$	[9]
EI-7	$e + N_2^+ + M \rightarrow N_2 + M$	$6\times10^{-27}\times(T/300)^{-1.5}$	[9]
EI-8	$e + NO^+ + M \rightarrow NO + M$	$6\times10^{-27}\times(T/300)^{-1.5}$	[9]
EI-9	$e + N^+ + M \rightarrow N + M$	$6\times10^{-27}\times(T/300)^{-1.5}$	[9]
EI-10	$e + O^+ + M \rightarrow O + M$	$6\times10^{-27}\times(T/300)^{-1.5}$	[9]
EI-11	$e + N_4^+ \rightarrow N_2 + N_2$	$2\times10^{-6}\times(T/300)^{-0.5}$	[9]
EI-12	$e + N_4^+ \rightarrow 2N + N_2$	$1.4\times10^{-6}\times(T/300)^{-0.41}$	[3]
EI-13	$e + O_4^+ \rightarrow O_2 + O_2$	$1.4\times10^{-6}\times(T/300)^{-0.5}$	[9]
EI-14	$e + O_4^+ \rightarrow 2O + O_2$	1.7×10^{-7}	[10]
EI-15	$e + NO^+ \rightarrow O + N$	$4\times10^{-7}\times(T/300)^{-1.5}$	[9]
EI-16	$e + NO^+ \rightarrow O + N(^2D)$	$3\times10^{-7}\times(T/300)^{-1}$	[9]
EI-17	$e + N^+ \rightarrow N$	$4\times10^{-12}\times(T/300)^{-0.58}$	[6]
EI-18	$e + O^+ \rightarrow O$	$3.24\times10^{-12}\times(T/300)^{-0.66}$	[6]
EI-19	$e + NO^+(N_2) \rightarrow NO + N_2$	$1.3\times10^{-6}\times(T/300)^{-0.5}$	[9]
EI-20	$e + NO^+(O_2) \rightarrow NO + O_2$	$1.3\times10^{-6}\times(T/300)^{-0.5}$	[9]
EI-21	$e + N_2O_2^+ \rightarrow O_2 + N_2$	$1.3\times10^{-6}\times(T/300)^{-0.5}$	[9]
EI-22	$e + NO_2^+ \rightarrow NO + O$	$2\times10^{-7}\times(T/300)^{-0.5}$	[9]
EI-23	$e + N_2O^+ \rightarrow O + N_2$	$1.3\times10^{-6}\times(T/300)^{-0.5}$	[9]
EI-24	$e + N_3^+ \rightarrow N + N_2$	$3.5\times10^{-6}\times(T/300)^{-0.5}$	[3]
EI-25	$e + N_3^+ \rightarrow N + N_2(A)$	$4.30\times10^{-7}\times(T/300)^{-0.5}$	[3]
EI-26	$e + N_3^+ \rightarrow N + N_2(B)$	$4.30\times10^{-7}\times(T/300)^{-0.5}$	[3]
EI-27	$e + H_2O^+ \rightarrow O + 2H$	$3.05\times10^{-7}\times(T/300)^{-0.5}$	[17]
EI-28	$e + H_2O^+ \rightarrow OH + H$	$8.6\times10^{-8}\times(T/300)^{-0.5}$	[17]
EI-29	$e + H_2O^+ \rightarrow O + H_2$	$3.9\times10^{-8}\times(T/300)^{-0.5}$	[17]
EI-30	$e + OH^+ \rightarrow O + H$	$3.75\times10^{-8}\times(T/300)^{-0.5}$	[17]
EI-31	$e + H^+(H_2O) \rightarrow OH + 2H$	$2.58\times10^{-7}\times(T/300)^{-0.5}$	[17]
EI-32	$e + H^+(H_2O) \rightarrow H + H_2O$	$1.08\times10^{-7}\times(T/300)^{-0.5}$	[17]
EI-33	$e + H^+(H_2O) \rightarrow OH + H_2$	$6.02\times10^{-8}\times(T/300)^{-0.5}$	[17]
EI-34	$e + H^+(H_2O) \rightarrow O + H + H_2$	$5.6\times10^{-9}\times(T/300)^{-0.5}$	[17]
EI-35	$e + H^+(H_2O)_2 \rightarrow H + 2H_2O$	$2.6\times10^{-6}\times(T/300)^{-0.5}$	[6]
EI-36	$e + H^+(H_2O)_3 \rightarrow H + 3H_2O$	$3.8\times10^{-6}\times(T/300)^{-0.5}$	[6]

EI-37	$e + H^+(H_2O)_4 \rightarrow H + 4H_2O$	$4.9\times10^{-6}\times(T/300)^{-0.5}$	[6]
EI-38	$e + H^+(H_2O)_5 \rightarrow H + 5H_2O$	$5\times10^{-6}\times(T/300)^{-0.5}$	[6]
EI-39	$e + H^+(H_2O)_6 \rightarrow H + 6H_2O$	$6.2\times10^{-6}\times(T/300)^{-0.5}$	[6]
EI-40	$e + H^+(H_2O)_7 \rightarrow H + 7H_2O$	$8.27\times10^{-6}\times(T/300)^{-0.5}$	[6]
EI-41	$e + H^+(H_2O)(OH) \rightarrow H + H_2O + OH$	$1.5\times10^{-6}\times(T/300)^{-0.5}$	[6]
EI-42	$e + H^+(H_2O)(CO_2) \rightarrow H + H_2O + CO_2$	$2\times10^{-6}\times(T/300)^{-0.5}$	[6]
EI-43	$e + H^+(H_2O)_2(CO_2) \rightarrow H + 2H_2O + CO_2$	$3\times10^{-6}\times(T/300)^{-0.5}$	[6]
EI-44	$e + H^+(H_2O)(N_2) \rightarrow H + H_2O + N_2$	$1.5\times10^{-6}\times(T/300)^{-0.5}$	[6]
EI-45	$e + H^+(H_2O)_2(N_2) \rightarrow H + 2H_2O + N_2$	$1.5\times10^{-6}\times(T/300)^{-0.5}$	[6]
EI-46	$e + O_2^+(H_2O) \rightarrow H_2O + O_2$	$2\times10^{-6}\times(T/300)^{-0.5}$	[6]
EI-47	$e + NO^+(H_2O) \rightarrow NO + H_2O$	$1.5\times10^{-6}\times(T/300)^{-0.5}$	[6]
EI-48	$e + NO^+(H_2O)_2 \rightarrow NO + 2H_2O$	$2\times10^{-6}\times(T/300)^{-0.5}$	[6]
EI-49	$e + NO^+(H_2O)_3 \rightarrow NO + 3H_2O$	$2\times10^{-6}\times(T/300)^{-0.5}$	[6]
EI-50	$e + NO^+(CO_2) \rightarrow NO + CO_2$	$1.5\times10^{-6}\times(T/300)^{-0.5}$	[6]
EI-51	$e + NO^+(H_2O)(CO_2) \rightarrow NO + H_2O + CO_2$	$2\times10^{-6}\times(T/300)^{-0.5}$	[6]
EI-52	$e + NO^+(H_2O)_2(CO_2) \rightarrow NO + 2H_2O + CO_2$	$2\times10^{-6}\times(T/300)^{-0.5}$	[6]
EI-53	$e + NO^+(H_2O)(N_2) \rightarrow NO + H_2O + N_2$	$2\times10^{-6}\times(T/300)^{-0.5}$	[6]
EI-54	$e + NO^+(H_2O)_2(N_2) \rightarrow NO + 2H_2O + N_2$	$2\times10^{-6}\times(T/300)^{-0.5}$	[6]
Ion-ion recombination			
II-1	$A^- + B^+ \rightarrow A + B$ for $A^- = [O^-, O_2^-, O_3^-, NO^-, NO_2^-, NO_3^-]$ and $B^+ = [O^+, O_2^+, N^+, N_2^+, NO^+, NO_2^+, N_2O^+]$	$2\times10^{-7}\times(T/300)^{-0.5}$	[9]
II-2	$A^- + (BC)^+ \rightarrow A + B + C$ for $A^- = [O^-, O_2^-, O_3^-, NO^-, NO_2^-, NO_3^-]$ and $(BC)^+ = [N_2^+, O_2^+, NO^+, NO_2^+, N_2O^+, N_3^+, N_4^+, NO^+(N_2), NO^+(O_2), N_2O_2^+]$	10^{-7}	[9]
II-3	$O_4^- + A^+ \rightarrow 2O_2 + A$ for $A^+ = [N^+, N_2^+, O^+, O_2^+, NO^+, NO_2^+, N_2O^+]$	10^{-7}	[9]
II-4	$O_4^- + (AB)^+ \rightarrow 2O_2 + A + B$ for $(AB)^+ = [N_3^+, N_4^+, O_4^+, NO^+(N_2), NO^+(O_2), N_2O_2^+]$	10^{-7}	[9]
II-5	$A^- + B^+ + M \rightarrow A + B + M$ for $A^- = [O^-, O_2^-]$ and $B^+ = [O^+, O_2^+, N^+, N_2^+, NO^+]$	$2\times10^{-25}\times(T/300)^{-2.5}$	[9]
II-6	$A^- + B^+ + M \rightarrow AB + M$ for $A^- = O_2^-$ and $B^+ = [O^+, N^+, NO^+]$	$2\times10^{-25}\times(T/300)^{-2.5}$	[9]
II-7	$A^- + B^+ + M \rightarrow AB + M$ for $A^- = O^-$ and $B^+ = [O^+, O_2^+, N^+, N_2^+, NO^+]$	$2\times10^{-25}\times(T/300)^{-2.5}$	[9]
II-8a	$X^- + Y^+ \rightarrow X + Y$	$6\times10^{-8}\times(T/300)^{-0.5}$	[1]
II-8b	$X^- + Y^+ + M \rightarrow X + Y + M$ for all X^-/Y^+ combinations not included in (II-1)–(II-7)	$1.25\times10^{-25}\times(T/300)^{-4}$	[1]
Neutral chemistry			
C-1	$N + O_2 \rightarrow NO + O$	$1.5\times10^{-11}\times\exp(-3600/T)$	[14]
C-2	$N + O_3 \rightarrow NO + O_2$	10^{-16}	[14]
C-3	$N + NO \rightarrow O + N_2$	$2.1\times10^{-11}\times\exp(-100/T)$	[14]
C-4	$N + NO_2 \rightarrow N_2O + O$	3×10^{-12}	[9]
C-5	$N + NO_2 \rightarrow NO + NO$	2.3×10^{-12}	[9]
C-6	$N + NO_2 \rightarrow 2O + N_2$	9.1×10^{-13}	[9]
C-7	$N + NO_2 \rightarrow N_2 + O_2$	7×10^{-13}	[9]
C-8	$N + N + M \rightarrow N_2 + M$	$8.27\times10^{-34}\times\exp(500/T)$	[9]
C-9	$N + O + M \rightarrow NO + M$	$1.76\times10^{-31}\times T^{-0.5}$	[9]
C-10	$O + O_3 \rightarrow O_2 + O_2$	$8\times10^{-12}\times\exp(-2060/T)$	[14]
C-11	$O + NO_2 \rightarrow NO + O_2$	$5.1\times10^{-12}\times\exp(210/T)$	[14]
C-12	$O + NO_3 \rightarrow NO_2 + O_2$	10^{-11}	[14]
C-13	$O + O + N_2 \rightarrow O_2 + N_2$	$2.76\times10^{-34}\times\exp(720/T)$	[15]
C-14	$O + O + O_2 \rightarrow O_2 + O_2$	$3.81\times10^{-33}\times(T/300)^{-0.63}$	[15]

C-15	$O + O_2 + N_2 \rightarrow O_3 + N_2$	$6.2\times10^{-34}\times(T/300)^{-2}$	[9]
C-16	$O + O_2 + O_2 \rightarrow O_3 + O_2$	$6.9\times10^{-34}\times(T/300)^{-1.25}$	[9]
C-17	$O + O_3 + O_2 \rightarrow O_3 + O_3 + O_2$	$1.5\times10^{-34}\times\exp(750/T)$	[3]
C-18	$O + O + O_2 \rightarrow O_3 + O + O_2$	$2.15\times10^{-34}\times\exp(345/T)$	[3]
C-19	$O + NO_2 + M \rightarrow NO_3 + M$	$8.9\times10^{-32}\times(T/300)^{-2}$	[3]
C-20	$O + NO + N_2 \rightarrow NO_2 + N_2$	$1.2\times10^{-31}\times(T/300)^{-1.682}$	[3]
C-21	$O + NO + O_2 \rightarrow NO_2 + O_2$	$9.3\times10^{-32}\times(T/300)^{-1.682}$	[3]
C-22	$O + NO \rightarrow NO_2$	$3.02\times10^{-11}\times(T/300)^{-0.75}$	[3]
C-23	$NO + NO_3 \rightarrow NO_2 + NO_2$	$1.5\times10^{-11}\times\exp(170/T)$	[14]
C-24	$NO + O_3 \rightarrow NO_2 + O_2$	$3\times10^{-12}\times\exp(-1500/T)$	[14]
C-25	$NO_2 + O_3 \rightarrow NO_3 + O_2$	$1.2\times10^{-13}\times\exp(-2450/T)$	[14]
C-26	$NO_2 + NO_3 \rightarrow NO + NO_2 + O_2$	$2.3\times10^{-13}\times\exp(-1600/T)$	[9]
C-27	$NO_2 + NO_3 + M \rightarrow N_2O_5 + M$	$5.9\times10^{-29}\times(T/300)^{-1.27}$	[3]
C-28	$NO_3 + NO_3 \rightarrow NO_2 + NO_2 + O_2$	$8.5\times10^{-13}\times\exp(-2450/T)$	[14]
C-29	$H + O_2 + M \rightarrow HO_2 + M$	$5.94\times10^{-32}\times(T/300)^{-1}$	[3]
C-30	$H + H_2 + O_2 \rightarrow HO_2 + H_2 + O_2$	$5.79\times10^{-32}\times(T/300)^{-0.8}$	[3]
C-31	$H + OH + M \rightarrow H_2O + M$	$6.88\times10^{-31}\times(T/300)^{-2}$	[3]
C-32	$H + NO_2 \rightarrow NO + OH$	$2.2\times10^{-10}\times\exp(-182/T)$	[3]
C-33	$H + O_3 \rightarrow OH(v) + O_2$	$1.4\times10^{-10}\times\exp(-470/T)$	[15]
C-34	$O + HO_2 \rightarrow OH(v) + O_2$	$3\times10^{-11}\times(1.-0.52)$	18
C-35	$O + HO_2 \rightarrow OH + O_2$	$3\times10^{-11}\times0.52$	[11]
C-36	$OH(v) + O \rightarrow H + O_2$	$2.5\times10^{-10}\times(T/300)^{0.5}$	[15]
C-37	$OH(v) + M \rightarrow OH + M$	$10^{-13}\times(T/300)^{0.5}$	[15]
C-38	$H + O_3 \rightarrow HO_2 + O$	7.5×10^{-13}	[3]
C-39	$H + HO_2 \rightarrow OH + OH$	$2.35\times10^{-10}\times\exp(-373.7/T)$	[3]
C-40	$H + HO_2 \rightarrow O + H_2O$	$9.18\times10^{-11}\times\exp(-971.9/T)$	[3]
C-41	$H + HO_2 \rightarrow H_2 + O_2$	$2.57\times10^{-11}\times(T/300)^{0.5598}\times\exp(-346/T)$	[3]
C-42	$H + NO_3 \rightarrow NO_2 + OH$	$5.8\times10^{-10}\times\exp(-750/T)$	[3]
C-43	$OH + OH \rightarrow H_2O + O$	$1.55\times10^{-13}\times(T/300)^{1.408}\times\exp(267.3/T)$	[3]
C-44	$OH + O \rightarrow H + O_2$	$2.1\times10^{-11}\times(T/300)^{-0.186}\times\exp(-153.9/T)$	[3]
C-45	$OH + H_2 \rightarrow H_2O + H$	$2.31\times10^{-12}\times(T/300)^{1.47}\times\exp(-1761/T)$	[3]
C-46	$OH + O_3 \rightarrow HO_2 + O_2$	$1.47\times10^{-12}\times\exp(-932.7/T)$	[3]
C-47	$OH + HO_2 \rightarrow H_2O + O_2$	$4.38\times10^{-11}\times\exp(110.9/T)$	[3]
C-48	$OH + HNO_2 \rightarrow H_2O + NO_2$	$1.8\times10^{-11}\times\exp(-390/T)$	[3]
C-49	$OH + N \rightarrow NO + H$	$3.92\times10^{-11}\times\exp(72.3/T)$	[3]
C-50	$OH + NO + M \rightarrow HNO_2 + M$	$7.4\times10^{-31}\times(T/300)^{-2.4}$	[3]
C-51	$OH + NO_2 + N_2 \rightarrow HNO_3 + N_2$	$2.6\times10^{-30}\times(T/300)^{-2.9}$	[3]
C-52	$OH + NO_2 + O_2 \rightarrow HNO_3 + O_2$	$2.2\times10^{-30}\times(T/300)^{-2.9}$	[3]
C-53	$OH + NO_3 \rightarrow HO_2 + NO_2$	2.2×10^{-11}	[3]
C-54	$OH + HNO_3 \rightarrow H_2O + NO_3$	$7.2\times10^{-15}\times\exp(785/T)$	[3]
C-55	$OH + HO_2 \rightarrow H_2O + O_2$	$1.7\times10^{-11}\times\exp(416/T)$	[15]
C-56	$HO_2 + O_3 \rightarrow OH + O_2 + O_2$	$1.66\times10^{-13}\times\exp(-1409.6/T)$	[3]
C-57	$HO_2 + NO \rightarrow OH + NO_2$	$3.6\times10^{-12}\times\exp(240/T)$	[3]
C-58	$HO_2 + NO_2 \rightarrow HNO_2 + O_2$	1.2×10^{-13}	[3]
C-59	$HO_2 + NO_3 \rightarrow HNO_3 + O_2$	9.21×10^{-13}	[3]
C-60	$HO_2 + N \rightarrow OH + NO$	2.19×10^{-11}	[3]
C-61	$N_2O_5 + H_2O \rightarrow HNO_3 + HNO_3$	5×10^{-19}	[3]
C-62	$N_2O_5 + O \rightarrow N_2 + 3O_2$	$3\times10^{-16}\times(T/300)^{0.5}$	[3]
C-63	$HNO_2 + O \rightarrow OH + NO_2$	$10^{-12}\times\exp(-2000/T)$	[3]
C-64	$HNO_2 + NO_3 \rightarrow HNO_3 + NO_2$	2×10^{-15}	[3]
C-65	$H + NO + M \rightarrow HNO + M$	$7.32\times10^{-32}\times(T/300)^{-1.318}\times\exp(-184.3/T)$	[3]
C-66	$HO_2 + NO \rightarrow HNO + O_2$	$9.1\times10^{-19}\times(T/300)\times\exp(2819/T)$	[3]
C-67	$HNO + H \rightarrow NO + H_2$	$2.35\times10^{-11}\times(T/300)^{0.94}\times\exp(-249/T)$	[3]
C-68	$HNO + OH \rightarrow H_2O + NO$	$1.26\times10^{-11}\times(T/300)^{0.99}\times\exp(-334.2/T)$	[3]
C-69	$OH + OH + M \rightarrow H_2O_2 + M$	$6.05\times10^{-31}\times(T/300)^{-3}$	[3]
C-70	$HO_2 + HO_2 \rightarrow H_2O_2 + O_2$	$8.05\times10^{-11}\times(T/300)^{-1}$	[3]
C-71	$HO_2 + HO_2 + M \rightarrow H_2O_2 + O_2 + M$	$1.9\times10^{-33}\times\exp(980/T)$	[3]

C-72	$H_2O_2 + H \rightarrow OH + H_2O$	$4\times10^{-11}\times\exp(-2000/T)$	[3]
C-73	$H_2O_2 + H \rightarrow HO_2 + H_2$	$8\times10^{-11}\times\exp(-4000/T)$	[3]
C-74	$H_2O_2 + OH \rightarrow H_2O + HO_2$	$4.53\times10^{-12}\times\exp(-288.9/T)$	[3]
C-75	$H_2O_2 + O \rightarrow OH + HO_2$	$1.79\times10^{-13}\times(T/300)^{2.92}\times\exp(-1394/T)$	[3]
C-76	$H_2O_2 + NO_3 \rightarrow HO_2 + HNO_3$	4.1×10^{-16}	[3]
C-77	$Cl + O_3 \rightarrow ClO + O_2$	$2.3\times10^{-11}\times\exp(-200/T)$	[14]
C-78	$Cl + H_2O_2 \rightarrow HCl + HO_2$	$1.1\times10^{-11}\times\exp(-980/T)$	[14]
C-79	$Cl + H_2 \rightarrow HCl + H$	$3.05\times10^{-11}\times\exp(-2270/T)$	[14]
C-80	$Cl + HO_2 \rightarrow HCl + O_2$	$1.4\times10^{-11}\times\exp(270/T)$	[14]
C-81	$Cl + HO_2 \rightarrow ClO + OH$	$3.6\times10^{-11}\times\exp(-375/T)$	[14]
C-82	$ClO + O \rightarrow Cl + O_2$	$2.8\times10^{-11}\times\exp(85/T)$	[14]
C-83	$ClO + NO \rightarrow Cl + NO_2$	$6.4\times10^{-12}\times\exp(290/T)$	[14]
C-84	$ClO + OH \rightarrow Cl + HO_2$	$7.4\times10^{-12}\times\exp(-270/T)$	[14]
C-85	$ClO + OH \rightarrow HCl + O_2$	$6\times10^{-13}\times\exp(-230/T)$	[14]
C-86	$HCl + OH \rightarrow Cl + H_2O$	$1.8\times10^{-12}\times\exp(-250/T)$	[14]
C-87	$HCl + O \rightarrow Cl + OH$	$10^{-11}\times\exp(-3300/T)$	[14]
C-88	$N(^2D) + O_2 \rightarrow NO + O$	$1.5\times10^{-12}\times(T/300)^{0.5}$	[9]
C-89	$N(^2D) + O_2 \rightarrow NO + O(^1D)$	$6\times10^{-12}\times(T/300)^{0.5}$	[9]
C-90	$N(^2D) + N_2 \rightarrow N + N_2$	6×10^{-15}	[9]
C-91	$N(^2D) + O \rightarrow N + O(^1D)$	$4\times10^{-13}\times(T/300)^{0.5}$	[15]
C-92	$N(^2D) + O \rightarrow N + O$	$4.5\times10^{-13}\times(T/300)^{0.5}$	[15]
C-93	$N(^2D) + N_2O \rightarrow NO + N_2$	3.5×10^{-12}	[3]
C-94	$N(^2D) + NO \rightarrow O + N_2$	1.8×10^{-10}	[3]
C-95	$N(^2D) + NO \rightarrow N_2O$	6×10^{-11}	[9]
C-96	$N(^2P) + O_2 \rightarrow NO + O$	2.6×10^{-12}	[9]
C-97	$N(^2P) + N_2 \rightarrow N(^2D) + N_2$	2×10^{-18}	[9]
C-98	$N(^2P) + N \rightarrow N(^2D) + N$	1.8×10^{-12}	[9]
C-99	$N(^2P) + NO \rightarrow O + N_2$	3×10^{-11}	[3]
C-100	$O(^1D) + N_2 \rightarrow O + N_2$	$1.8\times10^{-11}\times\exp(107/T)$	[9]
C-101	$O(^1D) + O_2 \rightarrow O + O_2$	$6.4\times10^{-12}\times\exp(67/T)$	[9]
C-102	$O(^1D) + O_2 \rightarrow O + O_2(a)$	10^{-12}	[3]
C-103	$O(^1D) + O_2 \rightarrow O + O_2(b)$	$2.56\times10^{-11}\times\exp(67/T)$	[9]
C-104	$O(^1D) + O_3 \rightarrow 2O + O_2$	1.2×10^{-10}	[9]
C-105	$O(^1D) + O_3 \rightarrow O_2 + O_2$	1.2×10^{-10}	[9]
C-106	$O(^1D) + O_3 \rightarrow O + O_3$	2.41×10^{-10}	[3]
C-107	$O(^1D) + N_2O \rightarrow NO + NO$	7.2×10^{-11}	[9]
C-108	$O(^1D) + N_2O \rightarrow N_2 + O_2$	4.4×10^{-11}	[9]
C-109	$O(^1D) + N_2O \rightarrow O + N_2O$	10^{-12}	[3]
C-110	$O(^1D) + NO \rightarrow N + O_2$	1.7×10^{-10}	[9]
C-111	$O(^1D) + NO_2 \rightarrow NO + O_2$	3×10^{-10}	[3]
C-112	$O(^1D) + H_2O \rightarrow OH + OH$	2.19×10^{-10}	[3]
C-113	$O(^1D) + H_2O \rightarrow H_2 + O_2$	3.57×10^{-10}	[3]
C-114	$O(^1D) + H_2 \rightarrow OH + H$	1.1×10^{-10}	[3]
C-115	$O(^1D) + H_2O_2 \rightarrow H_2O + O_2$	5.2×10^{-10}	[3]
C-116	$O(^1S) + H_2O \rightarrow OH + OH$	5×10^{-10}	[3]
C-117	$O(^1S) + H_2O \rightarrow H_2 + O_2$	5×10^{-10}	[3]
C-118	$O(^1S) + H_2O \rightarrow O + H_2O$	3×10^{-10}	[3]
C-119	$O(^1S) + O_2 \rightarrow O + O_2$	$4.3\times10^{-12}\times\exp(-850/T)\times0.69$	[9]
C-120	$O(^1S) + O_2 \rightarrow O(^1D) + O_2$	$4.3\times10^{-12}\times\exp(-850/T)\times0.31$	[15]
C-121	$O(^1S) + N_2 \rightarrow O + N_2$	5×10^{-17}	[15]
C-122	$O(^1S) + O_3 \rightarrow O(^1D) + O + O_2$	2.9×10^{-10}	[9]
C-123	$O(^1S) + O_3 \rightarrow O_2 + O_2$	2.9×10^{-10}	[9]
C-124	$O(^1S) + O \rightarrow O(^1D) + O$	$5\times10^{-11}\times\exp(-301/T)$	[9]
C-125	$O(^1S) + NO \rightarrow O + NO$	1.8×10^{-10}	[9]
C-126	$O(^1S) + NO \rightarrow O(^1D) + NO$	3.2×10^{-10}	[9]
C-127	$O(^1S) + N_2O \rightarrow O + N_2O$	6.3×10^{-12}	[9]
C-128	$O(^1S) + N_2O \rightarrow O(^1D) + N_2O$	3.1×10^{-12}	[9]

C-129	$O(^1S) + O_2(a) \rightarrow O(^1D) + O_2(b)$	3.6×10^{-11}	[9]
C-130	$O(^1S) + O_2(a) \rightarrow O + O + O$	3.4×10^{-11}	[9]
C-131	$O_2(a) + N_2 \rightarrow O_2 + N_2$	1.4×10^{-19}	[3]
C-132	$O_2(a) + O_2 \rightarrow O_2 + O_2$	$2.2\times10^{-18}\times(T/300)^{0.8}$	[9]
C-133	$O_2(a) + O \rightarrow O + O_2$	7×10^{-16}	[9]
C-134	$O_2(a) + N \rightarrow O + NO$	$2\times10^{-14}\times\exp(-600/T)$	[9]
C-135	$O_2(a) + NO \rightarrow O + NO_2$	4.88×10^{-18}	[3]
C-136	$O_2(a) + NO \rightarrow O_2 + NO$	2.48×10^{-17}	[18]
C-137	$O_2(a) + O_3 \rightarrow O(^1D) + O_2 + O_2$	$5.2\times10^{-11}\times\exp(-2840/T)$	[15]
C-138	$O_2(a) + O_3 \rightarrow O + O_2 + O_2$	$9.7\times10^{-13}\times\exp(-1564/T)$	[9]
C-139	$O_2(a) + O_2(a) + O_2 \rightarrow O_3 + O_3 + O_2$	$10^{-31}\times(T/300)^{0.5}$	[15]
C-140	$O_2(a) + H_2O \rightarrow H_2O + O_2$	3×10^{-18}	[3]
C-141	$O_2(b) + N_2 \rightarrow O_2(a) + N_2$	$4.9\times10^{-15}\times\exp(-253/T)$	[9]
C-142	$O_2(b) + O_2 \rightarrow O_2(a) + O_2$	$3.73\times10^{-16}\times(T/300)^{2.4}\times\exp(-241/T)$	[3]
C-143	$O_2(b) + O \rightarrow O_2(a) + O_2$	8×10^{-14}	[9]
C-144	$O_2(b) + O \rightarrow O(^1D) + O_2$	$3.39\times10^{-11}\times(T/300)^{-0.1}\times\exp(-4201/T)$	[9]
C-145	$O_2(b) + O_3 \rightarrow 2O_2(a) + O$	1.8×10^{-11}	[3]
C-146	$O_2(b) + NO \rightarrow O_2(a) + NO$	4×10^{-14}	[9]
C-147	$O_2(b) + H_2O \rightarrow H_2O + O_2$	6.7×10^{-12}	[3]
C-148	$N_2(A) + N_2 \rightarrow N_2 + N_2$	3×10^{-18}	[9]
C-149	$N_2(A) + O_2 \rightarrow 2O + N_2$	$1.63\times10^{-12}\times(T/300)^{0.55}$	[15]
C-150	$N_2(A) + O_2 \rightarrow O + N_2O$	7.8×10^{-14}	[9]
C-151	$N_2(A) + O_2 \rightarrow O_2(a) + N_2$	1.29×10^{-12}	[15]
C-152	$N_2(A) + O_2 \rightarrow O_2(b) + N_2$	1.29×10^{-12}	[15]
C-153	$N_2(A) + O \rightarrow O(^1S) + N_2$	2.1×10^{-11}	[9]
C-154	$N_2(A) + O \rightarrow N(^2D) + NO$	7×10^{-12}	[9]
C-155	$N_2(A) + N \rightarrow N(^2P) + N_2$	5×10^{-11}	[9]
C-156	$N_2(A) + N \rightarrow N + N_2$	2×10^{-11}	[3]
C-157	$N_2(A) + NO \rightarrow N_2 + NO$	7×10^{-11}	[9]
C-158	$N_2(A) + N_2O \rightarrow N + NO + N_2$	10^{-11}	[9]
C-159	$N_2(A) + N_2(A) \rightarrow N_2(B) + N_2$	$3\times10^{-10}\times(T/300)^{0.5}$	[15]
C-160	$N_2(A) + N_2(A) \rightarrow N_2(C) + N_2$	$1.5\times10^{-10}\times(T/300)^{0.5}$	[15]
C-161	$N_2(A) + H_2O \rightarrow H + OH + N_2$	5×10^{-14}	[3]
C-162	$N_2(A) + O_2(a) \rightarrow N_2(B) + O_2$	$10^{-10}\times(T/300)^{0.5}$	[15]
C-163	$N_2(B) + O_2 \rightarrow O + O + N_2$	3×10^{-10}	[9]
C-164	$N_2(B) + N_2 \rightarrow N_2(A) + N_2$	3×10^{-11}	[3]
C-165	$N_2(B) + N_2 \rightarrow N_2 + N_2$	2×10^{-12}	[3]
C-166	$N_2(B) + NO \rightarrow N_2(A) + NO$	2.4×10^{-10}	[9]
C-167	$N + N + M \rightarrow N_2(B) + M$	$2.4\times10^{-33}\times(T/300)^{0.5}$	[15]
C-168	$N_2(C) + O_2 \rightarrow O(^1S) + O + N_2$	3×10^{-10}	[9]
C-169	$N_2(C) + N_2 \rightarrow N_2(a'^1) + N_2$	10^{-11}	[9]
C-170	$N_2(a'^1) + O_2 \rightarrow O + O + N_2$	2.8×10^{-11}	[9]
C-171	$N_2(a'^1) + N_2 \rightarrow N_2(B) + N_2$	4×10^{-15}	[5]
C-172	$N_2(a'^1) + NO \rightarrow N + O + N_2$	3.6×10^{-10}	[9]
C-173	$N_2(a^1) + O_2 \rightarrow O + O + N_2$	2.8×10^{-11}	[3]
C-174	$N_2(a^1) + N_2 \rightarrow N_2 + N_2$	2×10^{-13}	[3]
C-175	$N_2(a^1) + NO \rightarrow N + O + N_2$	3.6×10^{-10}	[3]
C-176	$N_2(a^1) + H_2O \rightarrow H + OH + N_2$	5×10^{-14}	[3]
C-177	$O_2 + h\nu \rightarrow O + O$	$f(h\nu)$	[2]
C-178	$O_3 + h\nu \rightarrow O_2 + O$	$f(h\nu)$	[2]
C-179	$O_3 + h\nu \rightarrow O_2 + O(^1D)$	$f(h\nu)$	[2]
C-180	$NO + h\nu \rightarrow N + O$	$f(h\nu)$	[2]
C-181	$NO_2 + h\nu \rightarrow NO + O$	$f(h\nu)$	[2]
C-182	$NO_3 + h\nu \rightarrow NO_2 + O$	$f(h\nu)$	[2]
C-183	$HNO_3 + h\nu \rightarrow NO_2 + OH$	$f(h\nu)$	[2]
C-184	$N_2O + h\nu \rightarrow O(^1D) + N_2$	$f(h\nu)$	[2]
C-185	$N_2O_5 + h\nu \rightarrow NO_2 + NO_3$	$f(h\nu)$	[2]

C-186	$N_2O_5 + h\nu \rightarrow O + NO + NO_2$	$f(h\nu)$	[2]
C-187	$H_2O + h\nu \rightarrow H + OH$	$f(h\nu)$	[2]
C-188	$HO_2 + h\nu \rightarrow O + OH$	$f(h\nu)$	[2]
C-189	$H_2O_2 + h\nu \rightarrow OH + OH$	$f(h\nu)$	[2]
C-190	$HCl + h\nu \rightarrow H + Cl$	$f(h\nu)$	[2]
C-190	$ClO + h\nu \rightarrow Cl + O$	$f(h\nu)$	[2]
Radiative de-excitation			
RA-1	$O(^1D) \rightarrow O + h\nu$	9.1×10^{-3}	[15]
RA-2	$O(^1S) \rightarrow O(^1D) + h\nu$	1.43	[15]
RA-3	$O_2(a) \rightarrow O_2 + h\nu$	2.22×10^{-4}	[15]
RA-4	$O_2(b) \rightarrow O_2 + h\nu$	7.7×10^{-2}	[15]
RA-5	$OH(v) \rightarrow OH + h\nu$	218	[15]
RA-6	$N_2(B) \rightarrow N_2(A) + h\nu$	1.5×10^{5}	[9]
RA-7	$N_2(C) \rightarrow N_2(B) + h\nu$	3×10^{7}	[9]
RA-8	$N_2(a^1) \rightarrow N_2 + h\nu$	$8.55\ \times10^{3}$	[3]
RA-9	$N(^2D) \rightarrow N + h\nu$	1.06×10^{-5}	[13]
RA-10	$N(^2P) \rightarrow N(^2D) + h\nu$	7.9×10^{-2}	[13]

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