

Rate constants for a reactive system of astrophysical interest: A statistical study of CH_2^+ . Supplementary Information Part B

Tomás González-Lezana^{1,*}, Maarten Konings², Jérôme Loreau², François Lique³,
Milan Sil⁴, and Alexandre Faure⁴

¹Instituto de Física Fundamental, IFF-CSIC, Serrano 123, 28006 Madrid, Spain

*Corresponding author. Email: t.gonzalez.lezana@csic.es

² KU Leuven, Department of Chemistry, Celestijnenlaan 200F, B-3001 Leuven,
Belgium

³ Université Rennes, CNRS, IPR (Institut de Physique de Rennes), UMR 6251,
F-35000 Rennes, France.

⁴Université Grenoble Alpes, Centre national de la Recherche Scientifique (CNRS),
Institut de Planétologie et d'Astrophysique de Grenoble (IPAG), 38000 Grenoble,
France

1 The $\text{CH}^+(v, j) + \text{H} \rightarrow \text{C}^+ + \text{H}_2(v')$ reaction

Table 1: Rate coefficients for $\text{H} + \text{CH}^+(v = 0, j = 0) \rightarrow \text{C}^+ + \text{H}_2(v')$ transitions. $\text{H}_2(j')$ parity adapted factors have been employed. See text of the manuscript for details.

T [K]	50	100	500	1000	1500
$(v' = 0)$	9.68(10)	9.81(10)	9.44(10)	8.74(10)	8.16(10)
$(v' = 1)$	2.89(22)	7.82(17)	6.92(12)	3.83(11)	7.17(11)
$(v' = 2)$	3.03(72)	7.51(42)	2.96(17)	4.70(14)	5.31(13)

Table 2: Same as Table 1 for $\text{H} + \text{CH}^+(v = 0, j = 1) \rightarrow \text{C}^+ + \text{H}_2(v')$ transitions.

T [K]	50	100	500	1000	1500
$(v' = 0)$	1.03(9)	1.04(9)	9.52(10)	8.65(10)	8.06(10)
$(v' = 1)$	1.83(21)	3.06(16)	1.07(11)	5.46(11)	1.00(10)
$(v' = 2)$	6.28(64)	1.43(38)	3.82(17)	5.71(14)	6.46(13)

Table 3: Same as Table 1 for $\text{H}+\text{CH}^+(v=0, j=2) \rightarrow \text{C}^+ + \text{H}_2(v')$ transitions.

T [K]	50	100	500	1000	1500
$(v'=0)$	9.74(10)	9.89(10)	9.14(10)	8.35(10)	7.81(10)
$(v'=1)$	1.96(21)	3.27(16)	1.12(11)	5.61(11)	1.02(10)
$(v'=2)$	1.08(63)	2.46(38)	4.30(17)	6.00(14)	6.70(13)

Table 4: Same as Table 1 for $\text{H}+\text{CH}^+(v=0, j=3) \rightarrow \text{C}^+ + \text{H}_2(v')$ transitions.

T [K]	50	100	500	1000	1500
$(v'=0)$	8.99(10)	9.13(10)	8.58(10)	7.93(10)	7.46(10)
$(v'=1)$	1.15(20)	7.04(16)	1.28(11)	5.95(11)	1.05(10)
$(v'=2)$	4.07(63)	9.26(38)	6.60(17)	7.04(14)	7.51(13)

Table 5: Same as Table 1 for $\text{H}+\text{CH}^+(v=0, j=4) \rightarrow \text{C}^+ + \text{H}_2(v')$ transitions.

T [K]	50	100	500	1000	1500
$(v'=0)$	8.30(10)	8.41(10)	7.94(10)	7.43(10)	7.05(10)
$(v'=1)$	1.55(19)	2.94(15)	1.64(11)	6.61(11)	1.12(10)
$(v'=2)$	6.67(63)	1.52(37)	9.01(17)	8.37(14)	8.59(13)

Table 6: Same as Table 1 for $\text{H}+\text{CH}^+(v=0, j=5) \rightarrow \text{C}^+ + \text{H}_2(v')$ transitions.

T [K]	50	100	500	1000	1500
$(v'=0)$	7.67(10)	7.76(10)	7.32(10)	6.96(10)	6.66(10)
$(v'=1)$	6.26(16)	2.15(13)	3.76(11)	9.37(11)	1.36(10)
$(v'=2)$	1.45(62)	3.29(37)	1.51(16)	1.08(13)	1.02(12)

Table 7: Same as Table 1 for $\text{H}+\text{CH}^+(v=0, j=6) \rightarrow \text{C}^+ + \text{H}_2(v')$ transitions.

T [K]	50	100	500	1000	1500
$(v'=0)$	7.12(10)	7.13(10)	6.68(10)	6.42(10)	6.21(10)
$(v'=1)$	1.47(15)	2.76(13)	3.80(11)	9.40(11)	1.36(10)
$(v'=2)$	2.15(62)	4.88(37)	2.06(16)	1.32(13)	1.19(12)

Table 8: Same as Table 1 for $\text{H}+\text{CH}^+(v=0, j=7) \rightarrow \text{C}^+ + \text{H}_2(v')$ transitions.

T [K]	50	100	500	1000	1500
$(v'=0)$	6.57(10)	6.56(10)	6.11(10)	5.93(10)	5.79(10)
$(v'=1)$	7.18(13)	4.52(12)	5.69(11)	1.09(10)	1.47(10)
$(v'=2)$	3.68(62)	8.36(37)	3.18(16)	1.74(13)	1.46(12)

Table 9: Same as Table 1 for $\text{H}+\text{CH}^+(v=0, j=8) \rightarrow \text{C}^+ + \text{H}_2(v')$ transitions.

T [K]	50	100	500	1000	1500
$(v'=0)$	5.91(10)	6.00(10)	5.63(10)	5.53(10)	5.42(10)
$(v'=1)$	3.13(11)	4.28(11)	9.44(11)	1.40(10)	1.73(10)
$(v'=2)$	6.50(53)	1.35(32)	7.92(16)	2.51(13)	1.90(12)

Table 10: Same as Table 1 for $\text{H}+\text{CH}^+(v=0, j=9) \rightarrow \text{C}^+ + \text{H}_2(v')$ transitions.

T [K]	50	100	500	1000	1500
$(v'=0)$	5.19(10)	5.40(10)	5.39(10)	5.42(10)	5.34(10)
$(v'=1)$	6.29(11)	6.61(11)	9.53(11)	1.25(10)	1.46(10)
$(v'=2)$	1.53(52)	3.20(32)	1.35(15)	2.99(13)	2.04(12)

Table 11: Same as Table 1 for $\text{H}+\text{CH}^+(v=0, j=10) \rightarrow \text{C}^+ + \text{H}_2(v')$ transitions.

T [K]	50	100	500	1000	1500
$(v'=0)$	5.04(10)	5.43(10)	5.23(10)	5.08(10)	4.96(10)
$(v'=1)$	8.38(11)	9.48(11)	1.14(10)	1.36(10)	1.51(10)
$(v'=2)$	3.27(52)	6.80(32)	2.47(15)	4.32(13)	2.59(12)

Table 12: Same as Table 1 for $\text{H}+\text{CH}^+(v=0, j=11) \rightarrow \text{C}^+ + \text{H}_2(v')$ transitions.

T [K]	50	100	500	1000	1500
$(v'=0)$	4.71(10)	5.42(10)	5.30(10)	5.01(10)	4.81(10)
$(v'=1)$	1.04(10)	1.20(10)	1.33(10)	1.50(10)	1.63(10)
$(v'=2)$	8.85(43)	1.68(27)	8.18(15)	7.10(13)	3.58(12)

Table 13: Same as Table 1 for $\text{H}+\text{CH}^+(v=0, j=12) \rightarrow \text{C}^+ + \text{H}_2(v')$ transitions.

T [K]	50	100	500	1000	1500
$(v'=0)$	3.86(10)	4.78(10)	4.93(10)	4.67(10)	4.49(10)
$(v'=1)$	1.01(10)	1.27(10)	1.52(10)	1.65(10)	1.74(10)
$(v'=2)$	2.24(42)	4.26(27)	1.62(14)	1.05(12)	4.71(12)

Table 14: Same as Table 1 for $\text{H}+\text{CH}^+(v=0, j=13) \rightarrow \text{C}^+ + \text{H}_2(v')$ transitions.

T [K]	50	100	500	1000	1500
$(v'=0)$	3.14(10)	4.21(10)	4.58(10)	4.39(10)	4.24(10)
$(v'=1)$	8.68(11)	1.35(10)	1.75(10)	1.78(10)	1.82(10)
$(v'=2)$	8.92(34)	1.58(23)	3.78(14)	1.70(12)	6.55(12)

Table 15: Same as Table 1 for $\text{H}+\text{CH}^+(v=0, j=14) \rightarrow \text{C}^+ + \text{H}_2(v')$ transitions.

T [K]	50	100	500	1000	1500
$(v'=0)$	2.32(10)	3.39(10)	4.07(10)	3.98(10)	3.89(10)
$(v'=1)$	8.76(11)	1.32(10)	1.68(10)	1.74(10)	1.79(10)
$(v'=2)$	2.26(32)	4.00(22)	1.50(13)	3.04(12)	9.38(12)

Table 16: Same as Table 1 for $\text{H}+\text{CH}^+(v=0, j=15) \rightarrow \text{C}^+ + \text{H}_2(v')$ transitions.

T [K]	50	100	500	1000	1500
$(v'=0)$	1.54(10)	2.46(10)	3.64(10)	3.72(10)	3.67(10)
$(v'=1)$	6.41(11)	1.07(10)	1.64(10)	1.74(10)	1.79(10)
$(v'=2)$	8.08(24)	1.35(18)	3.53(13)	5.01(12)	1.33(11)

Table 17: Same as Table 1 for $\text{H}+\text{CH}^+(v=0, j=16) \rightarrow \text{C}^+ + \text{H}_2(v')$ transitions.

T [K]	50	100	500	1000	1500
$(v'=0)$	1.16(10)	2.06(10)	3.63(10)	3.66(10)	3.57(10)
$(v'=1)$	4.75(11)	8.81(11)	1.72(10)	1.82(10)	1.85(10)
$(v'=2)$	2.24(22)	3.74(17)	1.46(12)	9.13(12)	1.91(11)

Table 18: Same as Table 1 for $\text{H}+\text{CH}^+(v=0, j=17) \rightarrow \text{C}^+ + \text{H}_2(v')$ transitions.

T [K]	50	100	500	1000	1500
$(v'=0)$	1.06(10)	1.92(10)	3.41(10)	3.42(10)	3.35(10)
$(v'=1)$	4.99(11)	9.51(11)	1.77(10)	1.84(10)	1.85(10)
$(v'=2)$	1.43(20)	2.63(16)	3.15(12)	1.48(11)	2.67(11)

Table 19: Same as Table 1 for $\text{H}+\text{CH}^+(v=0, j=18) \rightarrow \text{C}^+ + \text{H}_2(v')$ transitions.

T [K]	50	100	500	1000	1500
$(v'=0)$	7.95(11)	1.47(10)	3.05(10)	3.16(10)	3.12(10)
$(v'=1)$	3.72(11)	7.40(11)	1.66(10)	1.78(10)	1.80(10)
$(v'=2)$	1.26(14)	3.58(13)	1.24(11)	2.62(11)	3.79(11)

Table 20: Same as Table 1 for $\text{H}+\text{CH}^+(v=0, j=19) \rightarrow \text{C}^+ + \text{H}_2(v')$ transitions.

T [K]	50	100	500	1000	1500
$(v'=0)$	6.17(11)	1.18(10)	2.76(10)	2.95(10)	2.95(10)
$(v'=1)$	3.02(11)	5.90(11)	1.56(10)	1.74(10)	1.78(10)
$(v'=2)$	2.30(12)	6.00(12)	3.19(11)	4.58(11)	5.51(11)

Table 21: Same as Table 1 for $\text{H}+\text{CH}^+(v=0, j=20) \rightarrow \text{C}^+ + \text{H}_2(v')$ transitions.

T [K]	50	100	500	1000	1500
$(v'=0)$	4.81(11)	8.87(11)	2.42(10)	2.72(10)	2.76(10)
$(v'=1)$	2.47(11)	5.22(11)	1.57(10)	1.74(10)	1.76(10)
$(v'=2)$	5.45(12)	1.11(11)	4.21(11)	5.62(11)	6.48(11)

Table 22: Same as Table 1 for $\text{H}+\text{CH}^+(v=1, j=0) \rightarrow \text{C}^+ + \text{H}_2(v')$ transitions.

T [K]	50	100	500	1000	1500
$(v'=0)$	3.61(10)	3.71(10)	3.65(10)	3.66(10)	3.67(10)
$(v'=1)$	1.56(10)	1.52(10)	1.45(10)	1.56(10)	1.66(10)
$(v'=2)$	1.23(32)	2.17(22)	9.84(14)	2.49(12)	8.31(12)

Table 23: Same as Table 1 for $\text{H}+\text{CH}^+(v=1, j=1) \rightarrow \text{C}^+ + \text{H}_2(v')$ transitions.

T [K]	50	100	500	1000	1500
$(v'=0)$	3.56(10)	3.64(10)	3.61(10)	3.64(10)	3.64(10)
$(v'=1)$	1.47(10)	1.42(10)	1.40(10)	1.51(10)	1.61(10)
$(v'=2)$	1.22(32)	2.16(22)	9.51(14)	2.36(12)	7.90(12)

Table 24: Same as Table 1 for $\text{H}+\text{CH}^+(v=1, j=2) \rightarrow \text{C}^+ + \text{H}_2(v')$ transitions.

T [K]	50	100	500	1000	1500
$(v'=0)$	3.57(10)	3.61(10)	3.56(10)	3.59(10)	3.60(10)
$(v'=1)$	1.41(10)	1.37(10)	1.37(10)	1.49(10)	1.59(10)
$(v'=2)$	1.47(32)	2.59(22)	1.02(13)	2.06(12)	6.59(12)

Table 25: Same as Table 1 for $\text{H}+\text{CH}^+(v=1, j=3) \rightarrow \text{C}^+ + \text{H}_2(v')$ transitions.

T [K]	50	100	500	1000	1500
$(v'=0)$	3.53(10)	3.61(10)	3.52(10)	3.54(10)	3.54(10)
$(v'=1)$	1.41(10)	1.39(10)	1.38(10)	1.49(10)	1.59(10)
$(v'=2)$	1.79(32)	3.18(22)	1.25(13)	2.70(12)	8.57(12)

Table 26: Same as Table 1 for $\text{H}+\text{CH}^+(v=1, j=4) \rightarrow \text{C}^+ + \text{H}_2(v')$ transitions.

T [K]	50	100	500	1000	1500
$(v'=0)$	3.39(10)	3.41(10)	3.35(10)	3.41(10)	3.43(10)
$(v'=1)$	1.38(10)	1.34(10)	1.36(10)	1.47(10)	1.56(10)
$(v'=2)$	2.20(32)	3.89(22)	1.46(13)	2.96(12)	9.16(12)

Table 27: Same as Table 1 for $\text{H}+\text{CH}^+(v=1, j=5) \rightarrow \text{C}^+ + \text{H}_2(v')$ transitions.

T [K]	50	100	500	1000	1500
$(v'=0)$	3.57(10)	3.61(10)	3.56(10)	3.59(10)	3.60(10)
$(v'=1)$	1.41(10)	1.37(10)	1.37(10)	1.49(10)	1.59(10)
$(v'=2)$	1.47(32)	2.59(22)	1.02(13)	2.06(12)	6.59(12)

Table 28: Same as Table 1 for $\text{H}+\text{CH}^+(v=1, j=6) \rightarrow \text{C}^+ + \text{H}_2(v')$ transitions.

T [K]	50	100	500	1000	1500
$(v'=0)$	3.27(10)	3.23(10)	3.23(10)	3.32(10)	3.33(10)
$(v'=1)$	1.55(10)	1.47(10)	1.40(10)	1.51(10)	1.59(10)
$(v'=2)$	5.77(24)	9.66(19)	3.03(13)	4.47(12)	1.21(11)

Table 29: Same as Table 1 for $\text{H}+\text{CH}^+(v=1, j=7) \rightarrow \text{C}^+ + \text{H}_2(v')$ transitions.

T [K]	50	100	500	1000	1500
$(v'=0)$	3.15(10)	3.15(10)	3.21(10)	3.29(10)	3.28(10)
$(v'=1)$	1.50(10)	1.44(10)	1.45(10)	1.56(10)	1.63(10)
$(v'=2)$	8.86(23)	1.48(17)	7.31(13)	6.13(12)	1.45(11)

Table 30: Same as Table 1 for $\text{H}+\text{CH}^+(v=1, j=8) \rightarrow \text{C}^+ + \text{H}_2(v')$ transitions.

T [K]	50	100	500	1000	1500
$(v'=0)$	3.06(10)	3.15(10)	3.28(10)	3.27(10)	3.23(10)
$(v'=1)$	1.45(10)	1.44(10)	1.52(10)	1.59(10)	1.64(10)
$(v'=2)$	1.85(22)	3.05(17)	1.22(12)	8.04(12)	1.72(11)

Table 31: Same as Table 1 for $\text{H}+\text{CH}^+(v=1, j=9) \rightarrow \text{C}^+ + \text{H}_2(v')$ transitions.

T [K]	50	100	500	1000	1500
$(v'=0)$	3.28(10)	3.44(10)	3.31(10)	3.22(10)	3.16(10)
$(v'=1)$	1.68(10)	1.78(10)	1.64(10)	1.62(10)	1.64(10)
$(v'=2)$	3.35(22)	5.61(17)	1.96(12)	1.05(11)	2.06(11)

Table 32: Same as Table 1 for $\text{H}+\text{CH}^+(v=1, j=10) \rightarrow \text{C}^+ + \text{H}_2(v')$ transitions.

T [K]	50	100	500	1000	1500
$(v'=0)$	3.05(10)	3.33(10)	3.19(10)	3.09(10)	3.03(10)
$(v'=1)$	1.65(10)	1.77(10)	1.65(10)	1.65(10)	1.67(10)
$(v'=2)$	2.33(20)	6.11(16)	3.67(12)	1.48(11)	2.57(11)

Table 33: Same as Table 1 for $\text{H}+\text{CH}^+(v=1, j=11) \rightarrow \text{C}^+ + \text{H}_2(v')$ transitions.

T [K]	50	100	500	1000	1500
$(v'=0)$	2.71(10)	3.14(10)	3.09(10)	2.99(10)	2.93(10)
$(v'=1)$	1.46(10)	1.67(10)	1.65(10)	1.65(10)	1.66(10)
$(v'=2)$	2.07(16)	5.36(14)	7.93(12)	2.05(11)	3.14(11)

Table 34: Same as Table 1 for $\text{H}+\text{CH}^+(v=1, j=12) \rightarrow \text{C}^+ + \text{H}_2(v')$ transitions.

T [K]	50	100	500	1000	1500
$(v'=0)$	2.28(10)	2.83(10)	2.98(10)	2.91(10)	2.86(10)
$(v'=1)$	1.33(10)	1.65(10)	1.63(10)	1.60(10)	1.62(10)
$(v'=2)$	1.34(12)	4.32(12)	1.80(11)	2.97(11)	3.98(11)

Table 35: Same as Table 1 for $\text{H}+\text{CH}^+(v=1, j=13) \rightarrow \text{C}^+ + \text{H}_2(v')$ transitions.

T [K]	50	100	500	1000	1500
$(v'=0)$	1.95(10)	2.63(10)	2.87(10)	2.80(10)	2.76(10)
$(v'=1)$	1.05(10)	1.44(10)	1.64(10)	1.65(10)	1.66(10)
$(v'=2)$	1.21(11)	1.76(11)	1.07(11)	5.25(12)	3.21(12)

Table 36: Same as Table 1 for $\text{H}+\text{CH}^+(v=1, j=14) \rightarrow \text{C}^+ + \text{H}_2(v')$ transitions.

T [K]	50	100	500	1000	1500
$(v'=0)$	1.48(10)	2.18(10)	2.65(10)	2.63(10)	2.61(10)
$(v'=1)$	7.82(11)	1.23(10)	1.69(10)	1.69(10)	1.68(10)
$(v'=2)$	2.03(11)	3.23(11)	4.25(11)	4.96(11)	5.68(11)

Table 37: Same as Table 1 for $\text{H}+\text{CH}^+(v=2, j=0) \rightarrow \text{C}^+ + \text{H}_2(v')$ transitions.

T [K]	50	100	500	1000	1500
$(v'=0)$	2.31(10)	2.35(10)	2.32(10)	2.38(10)	2.43(10)
$(v'=1)$	1.29(10)	1.27(10)	1.37(10)	1.45(10)	1.50(10)
$(v'=2)$	1.87(11)	2.11(11)	3.19(11)	4.16(11)	5.01(11)

Table 38: Same as Table 1 for $\text{H}+\text{CH}^+(v=2, j=1) \rightarrow \text{C}^+ + \text{H}_2(v')$ transitions.

T [K]	50	100	500	1000	1500
$(v'=0)$	1.58(10)	2.02(10)	2.28(10)	2.36(10)	2.41(10)
$(v'=1)$	8.52(11)	1.07(10)	1.35(10)	1.44(10)	1.50(10)
$(v'=2)$	1.18(11)	1.75(11)	3.12(11)	4.12(11)	4.98(11)

Table 39: Same as Table 1 for $\text{H}+\text{CH}^+(v=2, j=1) \rightarrow \text{C}^+ + \text{H}_2(v')$ transitions.

T [K]	50	100	500	1000	1500
$(v'=0)$	1.58(10)	2.02(10)	2.28(10)	2.36(10)	2.41(10)
$(v'=1)$	8.52(11)	1.07(10)	1.35(10)	1.44(10)	1.50(10)
$(v'=2)$	1.18(11)	1.75(11)	3.12(11)	4.12(11)	4.98(11)

Table 40: Same as Table 1 for $\text{H}+\text{CH}^+(v=2, j=2) \rightarrow \text{C}^+ + \text{H}_2(v')$ transitions.

T [K]	50	100	500	1000	1500
$(v'=0)$	2.25(10)	2.27(10)	2.25(10)	2.31(10)	2.36(10)
$(v'=1)$	1.24(10)	1.22(10)	1.34(10)	1.42(10)	1.47(10)
$(v'=2)$	1.99(11)	2.38(11)	3.08(11)	3.94(11)	4.77(11)

Table 41: Same as Table 1 for $\text{H}+\text{CH}^+(v=2, j=3) \rightarrow \text{C}^+ + \text{H}_2(v')$ transitions.

T [K]	50	100	500	1000	1500
$(v'=0)$	2.23(10)	2.24(10)	2.22(10)	2.29(10)	2.34(10)
$(v'=1)$	1.24(10)	1.23(10)	1.37(10)	1.42(10)	1.46(10)
$(v'=2)$	3.48(11)	3.23(11)	3.22(11)	4.02(11)	4.83(11)

Table 42: Same as Table 1 for $\text{H}+\text{CH}^+(v=2, j=4) \rightarrow \text{C}^+ + \text{H}_2(v')$ transitions.

T [K]	50	100	500	1000	1500
$(v'=0)$	2.21(10)	2.21(10)	2.21(10)	2.29(10)	2.34(10)
$(v'=1)$	1.31(10)	1.36(10)	1.41(10)	1.43(10)	1.46(10)
$(v'=2)$	3.56(11)	3.28(11)	3.29(11)	4.08(11)	4.89(11)

Table 43: Same as Table 1 for $\text{H}+\text{CH}^+(v=2, j=5) \rightarrow \text{C}^+ + \text{H}_2(v')$ transitions.

T [K]	50	100	500	1000	1500
$(v' = 0)$	2.20(10)	2.19(10)	2.21(10)	2.29(10)	2.33(10)
$(v' = 1)$	1.59(10)	1.54(10)	1.41(10)	1.41(10)	1.44(10)
$(v' = 2)$	3.66(11)	3.40(11)	3.63(11)	4.48(11)	5.25(11)