Table C.2 Chemical Thermodynamic Properties at 298.15 K and 1 bar[a]

Substance	$\Delta_f H°$ kJ mol^{-1}	$\Delta_f G°$ kJ mol^{-1}	$\overline{S}°$ J K^{-1} mol^{-1}	$\overline{C}_P°$ J K^{-1} mol^{-1}
O(g)	249.170	231.731	161.055	21.912
O_2(g)	0	0	205.138	29.355
O_3(g)	142.7	163.2	238.93	39.20
H(g)	217.965	203.247	114.713	20.784
H^+(g)	1536.202			
H^+(ao)	0	0	0	0
H_2(g)	0	0	130.684	28.824
OH(g)	38.95	34.23	183.745	29.886
OH^-(ao)	−229.994	−157.244	−10.75	−148.5
H_2O(l)	−285.830	−237.129	69.91	75.291
H_2O(g)	−241.818	−228.572	188.825	33.577
H_2O_2(l)	−187.78	−120.35	109.6	89.1
He(g)	0	0	126.150	20.786
Ne(g)	0	0	146.328	20.786
Ar(g)	0	0	154.843	20.786
Kr(g)	0	0	164.082	20.786
Xe(g)	0	0	169.683	20.786
F(g)	78.99	61.91	158.754	22.744
F^-(ao)	−332.63	−278.79	−13.8	−106.7
F_2(g)	0	0	202.78	31.30
HF(g)	−271.1	−273.2	173.779	29.133
Cl(g)	121.679	105.680	165.198	21.840
Cl^-(ao)	−167.159	−131.228	56.5	−136.4
Cl_2(g)	0	0	223.066	33.907
ClO_4^-(ao)	−129.33	−8.52	182.0	
HCl(g)	−92.307	−95.299	186.908	29.12
HCl(ai)	−167.159	−131.228	56.5	−136.4
HCl in 100H_2O	−165.925			

(*continued*)

[a] The values in Table C.2 are from The NBS Tables of Chemical Thermodynamic Properties (1982). The standard state pressure is 1 bar (0.1 MPa). The compounds are in the order of elements used in these tables. For the elements represented in Table C.2, this order is O, H, He, F, Cl, Br, I, S, N, P, C, Pb, Al, Zn, Cd, Hg, Cu, Ag, Fe, Ti, Mg, Ca, Li, Na, K, Rb, and Cs. The standard state for a strong electrolyte in aqueous solution is the ideal solution at unit mean molality (unit activity). The thermodynamic properties of the completely dissociated electrolyte are designated by ai. The thermodynamic properties of undissociated molecules in water are designated by ao. The properties of organic substances with more than two carbon atoms are from D. R. Stull, E. F. Westrum, and G. C. Sinke, *The Chemical Thermodynamics of Organic Compounds.* New York: Wiley, 1969. The NBS Tables of Chemical Thermodynamic Properties have been published as a supplement to Volume II (1982) of the *Journal of Physical and Chemical Reference Data* and may be ordered from the American Chemical Society, 1155 Sixteenth St., NW, Washington, DC 20036. The conversion to the new standard state pressure is described by R. D. Freeman, *J. Chem. Educ.* **62**:681 (1985).

Table C.2 *(continued)*

Substance	$\Delta_f H°$ kJ mol^{-1}	$\Delta_f G°$ kJ mol^{-1}	$\overline{S}°$ J K^{-1} mol^{-}	$\overline{C}_P°$ J K^{-1} mol
HCl in 200H_2O	−166.272			
Br(g)	111.884	82.396	175.022	20.786
Br^-(ao)	−121.55	−103.96	82.4	−141.8
Br_2(l)	0	0	152.231	75.689
Br_2(g)	30.907	3.110	245.463	36.02
HBr(g)	−36.40	−53.45	198.695	29.142
I(g)	106.838	70.250	180.791	20.786
I^-(ao)	−55.19	−51.57	111.3	−142.3
I_2(cr)	0	0	116.135	54.438
I_2(g)	62.438	19.317	260.69	36.90
HI(g)	26.48	1.70	206.594	29.158
S(rhombic)	0	0	31.80	22.64
S(monoclinic)	0.33	0.1	32.6	23.6
S(g)	278.805	238.250	167.821	23.673
S_2(g)	128.37	79.30	228.18	32.47
S^{2-}(ao)	33.1	85.8	−14.6	
SO_2(g)	−296.830	−300.194	248.22	39.87
SO_3(g)	−395.72	−371.06	256.76	50.67
SO_4^{2-}(ao)	−909.27	−744.53	2.01	−293
HS^-(ai)	−17.6	12.08	62.8	
H_2S(g)	−20.63	−33.56	205.79	34.23
H_2SO_4(l)	−813.989	−690.003	156.904	138.91
H_2SO_4(ai)	−909.27	−744.53	20.1	−293
N(g)	472.704	455.563	153.298	20.786
N_2(g)	0	0	191.61	29.125
NO(g)	90.25	86.57	210.761	29.844
NO_2(g)	33.18	51.31	240.06	37.20
NO_3^-(ao)	−205.0	−108.74	146.4	−86.6
N_2O(g)	82.05	104.20	219.85	38.45
N_2O_4(l)	−19.50	97.54	209.2	142.7
N_2O_4(g)	9.16	97.89	304.29	77.28
NH_3(g)	−46.11	−16.45	192.45	35.06
NH_3(ao)	−80.29	−26.50	111.3	
NH_4^+(ao)	−132.51	−79.31	113.4	79.9
HNO_3(l)	−174.10	−80.71	155.60	109.87
HNO_3(ai)	−207.36	−111.25	146.4	−86.6
NH_4OH(ao)	−366.121	−263.65	181.2	
P(s, white)	0	0	41.09	23.840
P(g)	314.64	278.25	163.193	20.786
P_2(g)	144.3	103.7	218.129	32.05
P_4(g)	58.91	24.44	279.98	67.15
PCl_3(g)	−287.0	−267.8	311.78	71.84
PCl_5(g)	−374.9	−305.0	364.58	112.8
C(graphite)	0	0	5.74	8.527
C(diamond)	1.895	2.900	2.377	6.113
C(g)	716.682	671.257	158.096	20.838
C_2(g)	0	−0.0330	144.960	29.196
CO(g)	−110.525	−137.168	197.674	29.142
CO_2(g)	−393.509	−394.359	213.74	37.11

Table C.2 (*continued*)

Substance	$\Delta_f H°$ kJ mol	$\Delta_f G°$ kJ mol^{-1}	$\overline{S}°$ J K^{-1} mol^{-1}	$\overline{C}_P°$ J K^{-1} mol^{-1}
CO_2(ao)	·413.80	385.98	117.6	
CO_3^{2-}(ao)	·677.14	527.81	−56.9	
CH(g)	595.8			
CH_2(g)	392.0			
CH_3(g)	138.9			
CH_4(g)	−74.81	−50.72	186.264	35.309
C_2H_2(g)	226.73	209.20	200.94	43.93
C_2H_4(g)	52.26	68.15	219.56	43.56
C_2H_6(g)	−84.68	−32.82	229.60	52.63
HCO_3^-(ao)	·691.99	−586.77	91.2	
HCHO(g)	·117	−113	218.77	35.40
HCO_2H(l)	·424.72	−361.35	128.95	99.04
H_2CO_3(ao)	·699.65	−623.08	187.4	
CH_3OH(l)	·238.66	−166.27	126.8	81.6
CH_3OH(g)	·200.66	−161.96	239.81	43.89
$CH_3CO_2^-$(ao)	·486.01	−369.31	86.6	−6.3
C_2H_4O (l, ethylene oxide)	−77.82	−11.76	153.85	87.95
CH_3CHO(l)	·192.30	−128.12	160.2	
CH_3CO_2H(l)	·484.5	−389.9	159.8	124.3
CH_3CO_2H(ao)	·485.76	−396.46	178.7	
C_2H_5OH(l)	·277.69	−174.78	160.7	111.46
C_2H_5OH(g)	·235.10	−168.49	282.70	65.44
$(CH_3)_2O$(g)	·184.05	−112.59	266.38	64.39
C_3H_6(g, propene)	20.42	62.78	267.05	63.89
C_3H_6(g, cyclopropane)	53.30	104.45	237.55	55.94
C_3H_8(g, propane)	·103.89	−23.38	270.02	73.51
C_4H_8(g, 1-butene)	−0.13	71.39	305.71	85.65
C_4H_8(g, 2-butene, cis)	−6.99	65.95	300.94	78.91
C_4H_8(g, 2-butene, trans)	−11.17	63.06	296.59	87.82
C_4H_{10}(g, butane)	·126.15	−17.03	310.23	97.45
C_4H_{10}(g, isobutane)	·134.52	−20.76	294.75	96.82
C_6H_6(g)	82.93	129.72	269.31	81.67
C_6H_{12}(g, cyclohexane)	·123.14	31.91	298.35	106.27
C_6H_{14}(g, hexane)	·167.19	−0.07	388.51	143.09
C_7H_8(g, toluene)	50.00	122.10	320.77	103.64
C_8H_8(g, styrene)	147.22	213.89	345.21	122.09
C_8H_{10}(g, ethylbenzene)	29.79	130.70	360.56	128.41
C_8H_{18}(g, octane)	−208.45	16.64	466.84	188.87
Si(s)	0	0	18.83	20.00
SiO_2(s, alpha)	−910.94	−856.64	41.84	44.43
Sn(s, white)	0	0	51.55	26.99
Sn^{2+}(ao)	−8.8	−27.2	−17	
SnO(s)	−285.8	−256.9	56.5	44.31
SnO_2(s)	−580.7	−519.6	52.3	52.59
Pb(s)	0	0	64.81	26.44
Pb^{2+}(ao)	−1.7	−24.43	10.5	
PbO(s, yellow)	−217.32	−187.89	68.70	45.77
PbO_2(s)	−277.4	−217.33	68.6	64.64

(*continued*)

Table C.2 *(continued)*

Substance	$\Delta_f H°$ kJ mol^{-1}	$\Delta_f G°$ kJ mol^{-1}	$\overline{S}°$ J K^{-1} mol^{-1}	$\overline{C}_P°$ J K^{-1} mol^{-1}
Al(s)	0	0	28.33	24.35
Al(g)	326.4	285.7	164.54	21.38
Al_2O_3(s, alpha)	−1675.7	−1582.3	50.92	79.04
$AlCl_3$(s)	−704.2	−628.8	110.67	91.84
Zn(s)	0	0	41.63	25.40
Zn^{2+}(ao)	−153.89	−147.06	−112.1	46
ZnO(s)	−348.28	−318.30	43.64	40.25
Cd(s, gamma)	0	0	51.76	25.98
Cd^{2+}(ao)	−75.90	−77.612	−73.2	
CdO(s)	−258.2	−228.4	54.8	43.43
$CdSO_4 \cdot \frac{8}{3}H_2O$(s)	−1729.4	−1465.141	229.630	213.26
Hg(l)	0	0	76.02	27.983
Hg(g)	61.317	31.820	174.96	20.786
Hg^{2+}(ao)	171.1	164.40	−32.2	
HgO(s, red)	−90.83	−58.539	70.29	44.06
Hg_2Cl_2(s)	−265.22	−210.745	192.5	102
Cu(s)	0	0	33.150	24.435
Cu^+(ao)	71.67	49.98	40.6	
Cu^{2+}(ao)	64.77	65.49	−99.6	
Ag(s)	0	0	42.55	25.351
Ag^+(ao)	105.579	77.107	72.68	21.8
Ag_2O(s)	−31.05	−11.20	121.3	65.86
AgCl(s)	−127.068	−109.789	96.2	50.79
Fe(s)	0	0	27.28	25.10
Fe^{2+}(ao)	−89.1	−78.90	−137.7	
Fe^{3+}(ao)	−48.5	−4.7	−315.9	
Fe_2O_3(s, hematite)	−824.2	−742.2	87.40	103.85
Fe_3O_4(s, magnetite)	−1118.4	−1015.4	146.4	143.43
Ti(s)	0	0	30.63	25.02
TiO_2(s)	−939.7	−884.5	49.92	55.48
U(s)	0	0	50.21	27.665
UO_2(s)	−1084.9	−1031.7	77.03	63.60
UO_2^{2+}(ao)	−1019.6	−953.5	−97.5	
UO_3(s, gamma)	−1223.8	−1145.9	96.11	81.67
Mg(s)	0	0	32.68	24.89
Mg(g)	147.70	113.10	148.650	20.786
Mg^{2+}(ao)	−466.85	−454.8	−138.1	
MgO(s)	−601.70	−569.43	26.94	37.15
$MgCl_2$(ao)	−801.15	−717.1	−25.1	
Ca(s)	0	0	41.42	25.31
Ca(g)	178.2	144.3	154.884	20.786
Ca^{2+}(ao)	−542.83	−553.58	−53.1	
CaO(s)	−635.09	−604.03	39.75	42.80
$CaCl_2$(ai)	−877.13	−816.01	59.8	
$CaCO_3$ (calcite)	−1206.92	−1128.79	92.9	81.88
$CaCO_3$ (aragonite)	−1207.13	−1127.75	88.7	81.25
Li(s)	0	0	29.12	24.77
Li^+(ao)	−278.49	−293.31	13.4	68.6

(continued)

Table C.2 (*continued*)

Substance	$\Delta_f H°$ kJ mol^{-1}	$\Delta_f G°$ kJ mol^{-1}	$\overline{S}°$ J K^{-1} mol^{-1}	$\overline{C}_P°$ J K^{-1} mol^{-1}
Na(s)	0	0	51.21	28.24
Na^+(ao)	−240.12	−261.905	59.0	46.4
NaOH(s)	−425.609	−379.494	64.455	59.54
NaOH(ai)	−470.114	−419.150	48.1	102.1
NaOH in 100H_2O	−469.646			
NaOH in 200H_2O	−469.608			
NaCl(s)	−411.153	−384.138	72.13	50.50
NaCl(ai)	−407.27	−393.133	115.5	−90.0
NaCl in 100H_2O	−407.066			
NaCl in 200H_2O	−406.923			
K(s)	0	0	64.18	29.58
K^+(ao)	−252.38	−283.27	102.5	21.8
KOH(s)	−424.764	−379.08	78.9	64.9
KOH(ai)	−482.37	−440.50	91.6	−126.8
KOH in 100H_2O	−481.637			
KOH in 200H_2O	−481.742			
KCl(s)	−436.747	−409.14	82.59	51.30
KCl(ai)	−419.53	−414.49	159.0	−114.6
KCl in 100H_2O	−419.320			
KCl in 200H_2O	−419.191			
Rb(s)	0	0	76.78	10.148
Rb^+(ao)	−251.17	−283.98	121.50	
Cs(s)	0	0	85.23	32.17
Cs^+(ao)	−258.28	−292.02	133.05	10.5