

# Appendix C

## Thermodynamic Quantities for Substances and Ions at 25°C

Substance or Ion	$\Delta H_f^\circ$ (kJ/mol)	$\Delta G_f^\circ$ (kJ/mol)	$S^\circ$ (J/K · mol)
$e^-(g)$	0	0	20.87
$H^+(g)$	1536.3	1517.1	108.83
$H^+(aq)$	0	0	0
$H(g)$	218.0	203.30	114.60
$H_2(g)$	0	0	130.6
<i>Group IA</i>			
$Li^+(g)$	687.163	649.989	132.91
$Li^+(aq)$	-278.46	-293.8	14
$Li(g)$	161	128	138.67
$Li(s)$	0	0	29.10
$LiF(s)$	-616.9	-588.7	35.66
$LiCl(s)$	-408	-384	59.30
$LiBr(s)$	-351	-342	74.1
$LiI(s)$	-270	-270	85.8
$Na^+(g)$	609.839	574.877	147.85
$Na^+(aq)$	-239.66	-261.87	60.2
$Na(g)$	107.76	77.299	153.61
$Na(s)$	0	0	51.446
$NaF(s)$	-575.4	-545.1	51.21
$NaCl(s)$	-411.1	-384.0	72.12
$NaBr(s)$	-361	-349	86.82
$NaI(s)$	-288	-285	98.5
$NaHCO_3(s)$	-947.7	-851.9	102
$Na_2CO_3(s)$	-1130.8	-1048.1	139
$K^+(g)$	514.197	481.202	154.47
$K^+(aq)$	-251.2	-282.28	103
$K(g)$	89.2	60.7	160.23
$K(s)$	0	0	64.672
$KF(s)$	-568.6	-538.9	66.55
$KCl(s)$	-436.68	-408.8	82.55
$KBr(s)$	-394	-380	95.94
$KI(s)$	-328	-323	106.39
$Rb^+(g)$	495.04		
$Rb^+(aq)$	-246	-282.2	124
$Rb(g)$	85.81	55.86	169.99
$Rb(s)$	0	0	69.5

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RbF(s)	-549.28		
RbCl(s)	-430.58		
RbBr(s)	-389.2	-378.1	108.3
RbI(s)	-328	-326	118.0
Cs <sup>+</sup> (g)	458.5	427.1	169.72
Cs <sup>+</sup> (aq)	-248	-282.0	133
Cs(g)	76.7	49.7	175.5
Cs(s)	0	0	85.15
CsF(s)	-554.7	-525.4	88
CsCl(s)	-442.8	-414	101.18
CsBr(s)	-395	-383	121
CsI(s)	-337	-333	130
<b>Group IIA</b>			
Mg <sup>2+</sup> (g)	2351		
Mg <sup>2+</sup> (aq)	-461.96	-456.01	-118
Mg <sup>+</sup> (g)	894.1		
Mg(g)	150	115	148.55
Mg(s)	0	0	32.69
MgCl <sub>2</sub> (s)	-641.6	-592.1	89.630
MgO(s)	-601.2	-569.0	26.9
Mg <sub>3</sub> N <sub>2</sub> (s)	-461	-401	88
MgCO <sub>3</sub> (s)	-1112	-1028	65.86
Ca <sup>2+</sup> (g)	1934.1		
Ca <sup>2+</sup> (aq)	-542.96	-553.04	-55.2
Ca <sup>+</sup> (g)	788.6		
Ca(g)	192.6	158.9	154.78
Ca(s)	0	0	41.6
CaF <sub>2</sub> (s)	-1215	-1162	68.87
CaCl <sub>2</sub> (s)	-795.0	-750.2	114
CaO(s)	-635.1	-603.5	38.2
CaCO <sub>3</sub> (s)	-1206.9	-1128.8	92.9
CaSO <sub>4</sub> (s)	-1432.7	-1320.3	107
Ca <sub>3</sub> (PO <sub>4</sub> ) <sub>2</sub> (s)	-4138	-3899	263
Sr <sup>2+</sup> (g)	1784		
Sr <sup>2+</sup> (aq)	-545.51	-557.3	-39
Sr <sup>+</sup> (g)	719.6		
Sr(g)	164	110	164.54
Sr(s)	0	0	54.4
SrCl <sub>2</sub> (s)	-828.4	-781.2	117
SrO(s)	-592.0	-562.4	55.5
SrCO <sub>3</sub> (s)	-1218	-1138	97.1
SrSO <sub>4</sub> (s)	-1445	-1334	122
Ba <sup>2+</sup> (g)	1649.9		
Ba <sup>2+</sup> (aq)	-538.36	-560.7	13
Ba <sup>+</sup> (g)	684.6		
Ba(g)	175.6	144.8	170.28
Ba(s)	0	0	62.5
BaCl <sub>2</sub> (s)	-806.06	-810.9	126
BaO(s)	-548.1	-520.4	72.07
BaCO <sub>3</sub> (s)	-1219	-1139	112
BaSO <sub>4</sub> (s)	-1465	-1353	132
<b>Group IIIA</b>			
B(β-rhombohedral)	0	0	5.87
B <sub>2</sub> O <sub>3</sub> (s)	-1272	-1193	53.8

Substance or Ion	$\Delta H_f^\circ$ (kJ/mol)	$\Delta G_f^\circ$ (kJ/mol)	$S^\circ$ (J/K · mol)
Al(s)	0	0	28.3
Al <sup>3+</sup> (aq)	-524.7	-481.2	-313
Al <sub>2</sub> O <sub>3</sub> (s)	-1676	-1582	50.94
<b>Group IVA</b>			
C(g)	715.0	669.6	158.0
C(graphite)	0	0	5.686
C(diamond)	1.896	2.866	2.439
CO(g)	-110.5	-137.2	197.5
CO <sub>2</sub> (g)	-393.5	-394.4	213.7
CO <sub>2</sub> (aq)	-412.9	-386.2	121
CO <sub>3</sub> <sup>2-</sup> (aq)	-676.26	-528.10	-53.1
HCO <sub>3</sub> <sup>-</sup> (aq)	-691.11	-587.06	95.0
H <sub>2</sub> CO <sub>3</sub> (aq)	-698.7	-623.42	191
CH <sub>4</sub> (g)	-74.87	-50.81	186.1
C <sub>2</sub> H <sub>2</sub> (g)	227	209	200.85
C <sub>2</sub> H <sub>4</sub> (g)	52.47	68.36	219.22
C <sub>2</sub> H <sub>6</sub> (g)	-84.667	-32.89	229.5
C <sub>6</sub> H <sub>6</sub> (l)	49.0	124.5	172.8
CH <sub>3</sub> OH(g)	-201.2	-161.9	238
CH <sub>3</sub> OH(l)	-238.6	-166.2	127
HCHO(g)	-116	-110	219
HCOO <sup>-</sup> (aq)	-410	-335	91.6
HCOOH(l)	-409	-346	129.0
HCOOH(aq)	-410	-356	164
C <sub>2</sub> H <sub>5</sub> OH(l)	-277.63	-174.8	161
CH <sub>3</sub> CHO(g)	-166	-133.7	266
CH <sub>3</sub> COOH(l)	-487.0	-392	160
CN <sup>-</sup> (aq)	151	166	118
HCN(g)	135	125	201.7
HCN(l)	105	121	112.8
HCN(aq)	105	112	129
CS <sub>2</sub> (g)	117	66.9	237.79
CS <sub>2</sub> (l)	87.9	63.6	151.0
CH <sub>3</sub> Cl(g)	-83.7	-60.2	234
CH <sub>2</sub> Cl <sub>2</sub> (l)	-117	-63.2	179
CHCl <sub>3</sub> (l)	-132	-71.5	203
CCl <sub>4</sub> (g)	-96.0	-53.7	309.7
CCl <sub>4</sub> (l)	-139	-68.6	214.4
COCl <sub>2</sub> (g)	-220	-206	283.74
Si(s)	0	0	18.0
SiO <sub>2</sub> (s)	-910.9	-856.5	41.5
Sn(gray)	3	4.6	44.8
Sn(white)	0	0	51.5
SnCl <sub>4</sub> (l)	-545.2	-474.0	259
Pb <sup>2+</sup> (aq)	1.6	-24.3	21
Pb(s)	0	0	64.785
PbO(s)	-218	-198	68.70
PbO <sub>2</sub> (s)	-276.6	-219.0	76.6
PbS(s)	-98.3	-96.7	91.3
PbCl <sub>2</sub> (s)	-359	-314	136
PbSO <sub>4</sub> (s)	-918.39	-811.24	147
<b>Group VA</b>			
N(g)	473	456	153.2
N <sub>2</sub> (g)	0	0	191.5
NO(g)	90.29	86.60	210.65
NO <sub>2</sub> (g)	33.2	51	239.9

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Substance or Ion	$\Delta H_f^\circ$ (kJ/mol)	$\Delta G_f^\circ$ (kJ/mol)	$S^\circ$ (J/K · mol)
N <sub>2</sub> O <sub>4</sub> (g)	9.16	97.7	304.3
N <sub>2</sub> O <sub>5</sub> (g)	11	118	346
NH <sub>3</sub> (g)	-45.9	-16 *	193
NH <sub>3</sub> (aq)	-80.83	26.7	110
NO <sub>3</sub> <sup>-</sup> (aq)	-206.57	-110.5	146
HNO <sub>3</sub> (l)	-173.23	-79.914	155.6
HNO <sub>3</sub> (aq)	-206.57	-110.5	146
P(g)	333.9	292.0	163.1
P(red)	0	0	22.8
P <sub>4</sub> (white)	68	48	164
P <sub>2</sub> (g)	179	127	218
P <sub>4</sub> (g)	129	72.5	280
PCl <sub>3</sub> (g)	-271	-258	312
PCl <sub>5</sub> (g)	-382	-313	353
P <sub>4</sub> O <sub>10</sub> (s)	-2942	-2675	229
PO <sub>4</sub> <sup>3-</sup> (aq)	-1266	-1013	-218
HPO <sub>4</sub> <sup>2-</sup> (aq)	-1281	-1082	-36
H <sub>2</sub> PO <sub>4</sub> <sup>-</sup> (aq)	-1285	-1135	89.1
H <sub>3</sub> PO <sub>4</sub> (aq)	-1277		
<b>Group VIA</b>			
O(g)	249.2	231.7	160.95
O <sub>2</sub> (g)	0	0	205.0
O <sub>3</sub> (g)	143	163	238.82
OH <sup>-</sup> (aq)	-229.94	-157.30	-10.54
H <sub>2</sub> O(g)	-241.826	-228.60	188.72
H <sub>2</sub> O(l)	-285.840	-237.192	69.940
H <sub>2</sub> O <sub>2</sub> (l)	-187.8	-120.4	110
H <sub>2</sub> O <sub>2</sub> (aq)	-191.2	-134.1	144
S(g)	279	239	168
S <sub>2</sub> (g)	129	80.1	228.1
S <sub>8</sub> (g)	101	49.1	430.211
S(rhombic)	0	0	31.9
S(monoclinic)	0.30	0.096	32.6
S <sup>2-</sup> (aq)	41.8	83.7	22
HS <sup>-</sup> (aq)	-17.7	12.6	61.1
H <sub>2</sub> S(g)	-20.2	-33	205.6
H <sub>2</sub> S(aq)	-39	-27.4	122
SO <sub>2</sub> (g)	-296.8	-300.2	248.1
SO <sub>3</sub> (g)	-396	-371	256.66
SO <sub>4</sub> <sup>2-</sup> (aq)	-907.51	-741.99	17
HSO <sub>4</sub> <sup>-</sup> (aq)	-885.75	-752.87	126.9
H <sub>2</sub> SO <sub>4</sub> (l)	-813.989	-690.059	156.90
H <sub>2</sub> SO <sub>4</sub> (aq)	-907.51	-741.99	17
<b>Group VIIA</b>			
F(g)	78.9	61.8	158.64
F <sup>-</sup> (g)	-255.6	-262.5	145.47
F <sup>-</sup> (aq)	-329.1	-276.5	-9.6
F <sub>2</sub> (g)	0	0	202.7
HF(g)	-273	-275	173.67
Cl(g)	121.0	105.0	165.1
Cl <sup>-</sup> (g)	-234	-240	153.25
Cl <sup>-</sup> (aq)	-167.46	-131.17	55.10
Cl <sub>2</sub> (g)	0	0	223.0
HCl(g)	-92.31	-95.30	186.79
HCl(aq)	-167.46	-131.17	55.06

Substance or Ion	$\Delta H_f^\circ$ (kJ/mol)	$\Delta G_f^\circ$ (kJ/mol)	$S^\circ$ (J/K · mol)
Br(g)	111.9	82.40	174.90
Br <sup>-</sup> (g)	-218.9		
Br <sup>-</sup> (aq)	-120.9	-102.82	80.71
Br <sub>2</sub> (g)	30.91	3.13	245.38
Br <sub>2</sub> (l)	0	0	152.23
HBr(g)	-36	-53.5	198.59
I(g)	106.8	70.21	180.67
I <sup>-</sup> (g)	-194.7		
I <sup>-</sup> (aq)	-55.94	-51.67	109.4
I <sub>2</sub> (g)	62.442	19.38	260.58
I <sub>2</sub> (s)	0	0	116.14
HI(g)	25.9	1.3	206.33
<b>Group IB</b>			
Cu <sup>+</sup> (aq)	51.9	50.2	-26
Cu <sup>2+</sup> (aq)	64.39	64.98	-98.7
Cu(g)	341.1	301.4	166.29
Cu(s)	0	0	33.1
Ag <sup>+</sup> (aq)	105.9	77.111	73.93
Ag(g)	289.2	250.4	172.892
Ag(s)	0	0	42.702
AgF(s)	-203	-185	84
AgCl(s)	-127.03	-109.72	96.11
AgBr(s)	-99.50	-95.939	107.1
AgI(s, II)	-62.38	-66.32	114
Ag <sub>2</sub> S(s)	-31.8	-40.3	146
<b>Group IIB</b>			
Zn <sup>2+</sup> (aq)	-152.4	-147.21	-106.5
Zn(g)	130.5	94.93	160.9
Zn(s)	0	0	41.6
ZnO(s)	-348.0	-318.2	43.9
ZnS(s, zinc blende)	-203	-198	57.7
Cd <sup>2+</sup> (aq)	-72.38	-77.74	-61.1
Cd(g)	112.8	78.20	167.64
Cd(s)	0	0	51.5
CdS(s)	-144	-141	71
Hg <sup>2+</sup> (aq)		164.8	
Hg <sub>2</sub> <sup>+</sup> (aq)		153.9	
Hg(g)	61.30	31.8	174.87
Hg(l)	0	0	76.027
HgCl <sub>2</sub> (s)	-230	-184	144
Hg <sub>2</sub> Cl <sub>2</sub> (s)	-264.9	-210.66	196
HgO(s)	-90.79	-58.50	70.27
<b>Group VIB</b>			
[Cr(H <sub>2</sub> O) <sub>6</sub> ] <sup>3+</sup> (aq)	-1971		
Cr(s)	0	0	23.8
CrO <sub>4</sub> <sup>2-</sup> (aq)	-863.2	-706.3	38
Cr <sub>2</sub> O <sub>7</sub> <sup>2-</sup> (aq)	-1461	-1257	214
<b>Group VIIB</b>			
Mn <sup>2+</sup> (aq)	-219	-223	-84
Mn(s, α)	0	0	31.8
MnO <sub>2</sub> (s)	-520.9	-466.1	53.1
MnO <sub>4</sub> <sup>-</sup> (aq)	-518.4	-425.1	190

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Substance or Ion	$\Delta H_f^\circ$ (kJ/mol)	$\Delta G_f^\circ$ (kJ/mol)	$S^\circ$ (J/K · mol)
<i>Group VIIIB</i>			
Fe <sup>3+</sup> (aq)	-47.7	-10.5	-293
Fe <sup>2+</sup> (aq)	-87.9	-84.94	113
Fe(s)	0	0	27.3
FeO(s)	-272.0	-251.4	60.75
Fe <sub>2</sub> O <sub>3</sub> (s)	-825.5	-743.6	87.400
Fe <sub>3</sub> O <sub>4</sub> (s)	-1121	-1018	145.3
Co <sup>2+</sup> (aq)	-67.4	-51.5	-155
Co(s)	0	0	30
Ni <sup>2+</sup> (aq)	-64.0	-46.4	-159
Ni(s)	0	0	30.1