

Standard Thermodynamic Values for Selected Substances*

Substance or Ion	ΔH_f° (kJ/mol)	ΔG_f° (kJ/mol)	S° (J/mol·K)	Substance or Ion	ΔH_f° (kJ/mol)	ΔG_f° (kJ/mol)	S° (J/mol·K)
$e^-(g)$	0	0	20.87	$CaCO_3(s)$	-1206.9	-1128.8	92.9
Aluminum				$CaO(s)$	-635.1	-603.5	38.2
Al(s)	0	0	28.3	$Ca(OH)_2(s)$	-986.09	-898.56	83.39
$Al^{3+}(aq)$	-524.7	-481.2	-313	$Ca_3(PO_4)_2(s)$	-4138	-3899	263
$AlCl_3(s)$	-704.2	-628.9	110.7	$CaSO_4(s)$	-1432.7	-1320.3	107
$Al_2O_3(s)$	-1676	-1582	50.94	Carbon			
Barium				C(graphite)	0	0	5.686
Ba(s)	0	0	62.5	C(diamond)	1.896	2.866	2.439
Ba(g)	175.6	144.8	170.28	C(g)	715.0	669.6	158.0
$Ba^{2+}(g)$	1649.9	—	—	CO(g)	-110.5	-137.2	197.5
$Ba^{2+}(aq)$	-538.36	-560.7	13	CO ₂ (g)	-393.5	-394.4	213.7
$BaCl_2(s)$	-806.06	-810.9	126	CO ₂ (aq)	-412.9	-386.2	121
$BaCO_3(s)$	-1219	-1139	112	$CO_3^{2-}(aq)$	-676.26	-528.10	-53.1
BaO(s)	-548.1	-520.4	72.07	$HCO_3^-(aq)$	-691.11	587.06	95.0
$BaSO_4(s)$	-1465	-1353	132	$H_2CO_3(aq)$	-698.7	-623.42	191
Boron				CH ₄ (g)	-74.87	-50.81	186.1
B(β-rhombohedral)	0	0	5.87	C ₂ H ₂ (g)	227	209	200.85
BF ₃ (g)	-1137.0	-1120.3	254.0	C ₂ H ₄ (g)	52.47	68.36	219.22
BCl ₃ (g)	-403.8	-388.7	290.0	C ₂ H ₆ (g)	-84.667	-32.89	229.5
B ₂ H ₆ (g)	35	86.6	232.0	C ₃ H ₈ (g)	-105	-24.5	269.9
B ₂ O ₃ (s)	-1272	-1193	53.8	C ₄ H ₁₀ (g)	-126	-16.7	310
H ₃ BO ₃ (s)	-1094.3	-969.01	88.83	C ₆ H ₆ (l)	49.0	124.5	172.8
Bromine				CH ₃ OH(g)	-201.2	-161.9	238
Br ₂ (l)	0	0	152.23	CH ₃ OH(l)	-238.6	-166.2	127
Br ₂ (g)	30.91	3.13	245.38	HCHO(g)	-116	-110	219
Br(g)	111.9	82.40	174.90	HCOO ⁻ (aq)	-410	-335	91.6
Br ⁻ (g)	-218.9	—	—	HCOOH(l)	-409	-346	129.0
Br ⁻ (aq)	-120.9	-102.82	80.71	HCOOH(aq)	-410	-356	164
HBr(g)	-36.3	-53.5	198.59	C ₂ H ₅ OH(g)	-235.1	-168.6	282.6
Cadmium				C ₂ H ₅ OH(l)	-277.63	-174.8	161
Cd(s)	0	0	51.5	CH ₃ CHO(g)	-166	-133.7	266
Cd(g)	112.8	78.20	167.64	CH ₃ COOH(l)	-487.0	-392	160
$Cd^{2+}(aq)$	-72.38	-77.74	-61.1	C ₆ H ₁₂ O ₆ (s)	-1273.3	-910.56	212.1
CdS(s)	-144	-141	71	C ₁₂ H ₂₂ O ₁₁ (s)	-2221.7	-1544.3	360.24
Calcium				CN ⁻ (aq)	151	166	118
Ca(s)	0	0	41.6	HCN(g)	135	125	201.7
Ca(g)	192.6	158.9	154.78	HCN(l)	105	121	112.8
$Ca^{2+}(g)$	1934.1	—	—	HCN(aq)	105	112	129
$Ca^{2+}(aq)$	-542.96	-553.04	-55.2	CS ₂ (g)	117	66.9	237.79
CaF ₂ (s)	-1215	-1162	68.87	CS ₂ (l)	87.9	63.6	151.0
CaCl ₂ (s)	-795.0	-750.2	114	CH ₃ Cl(g)	-83.7	-60.2	234
				CH ₂ Cl ₂ (l)	-117	-63.2	179

*All values at 298 K.

(continued)

Substance or Ion	ΔH_f° (kJ/mol)	ΔG_f° (kJ/mol)	S° (J/mol·K)	Substance or Ion	ΔH_f° (kJ/mol)	ΔG_f° (kJ/mol)	S° (J/mol·K)
CHCl ₃ (l)	−132	−71.5	203	Fe ²⁺ (aq)	−87.9	−84.94	113
CCl ₄ (g)	−96.0	−53.7	309.7	FeCl ₂ (s)	−341.8	−302.3	117.9
CCl ₄ (l)	−139	−68.6	214.4	FeCl ₃ (s)	−399.5	−334.1	142
COCl ₂ (g)	−220	−206	283.74	FeO(s)	−272.0	−251.4	60.75
Cesium				Fe ₂ O ₃ (s)	−825.5	−743.6	87.400
Cs(s)	0	0	85.15	Fe ₃ O ₄ (s)	−1121	−1018	145.3
Cs(g)	76.7	49.7	175.5	Lead			
Cs ⁺ (g)	458.5	427.1	169.72	Pb(s)	0	0	64.785
Cs ⁺ (aq)	−248	−282.0	133	Pb ²⁺ (aq)	1.6	−24.3	21
CsF(s)	−554.7	−525.4	88	PbCl ₂ (s)	−359	−314	136
CsCl(s)	−442.8	−414	101.18	PbO(s)	−218	−198	68.70
CsBr(s)	−395	−383	121	PbO ₂ (s)	−276.6	−219.0	76.6
CsI(s)	−337	−333	130	PbS(s)	−98.3	−96.7	91.3
Chlorine				PbSO ₄ (s)	−918.39	−811.24	147
Cl ₂ (g)	0	0	223.0	Lithium			
Cl(g)	121.0	105.0	165.1	Li(s)	0	0	29.10
Cl [−] (g)	−234	−240	153.25	Li(g)	161	128	138.67
Cl [−] (aq)	−167.46	−131.17	55.10	Li ⁺ (g)	687.163	649.989	132.91
HCl(g)	−92.31	−95.30	186.79	Li ⁺ (aq)	−278.46	−293.8	14
HCl(aq)	−167.46	−131.17	55.06	LiF(s)	−616.9	−588.7	35.66
ClO ₂ (g)	102	120	256.7	LiCl(s)	−408	−384	59.30
Cl ₂ O(g)	80.3	97.9	266.1	LiBr(s)	−351	−342	74.1
Chromium				LiI(s)	−270	−270	85.8
Cr(s)	0	0	23.8	Magnesium			
Cr ³⁺ (aq)	−1971	—	—	Mg(s)	0	0	32.69
CrO ₄ ^{2−} (aq)	−863.2	−706.3	38	Mg(g)	150	115	148.55
Cr ₂ O ₇ ^{2−} (aq)	−1461	−1257	214	Mg ²⁺ (g)	2351	—	—
Copper				Mg ²⁺ (aq)	−461.96	−456.01	118
Cu(s)	0	0	33.1	MgCl ₂ (s)	−641.6	−592.1	89.630
Cu(g)	341.1	301.4	166.29	MgCO ₃ (s)	−1112	−1028	65.86
Cu ⁺ (aq)	51.9	50.2	−26	MgO(s)	−601.2	−569.0	26.9
Cu ²⁺ (aq)	64.39	64.98	−98.7	Mg ₃ N ₂ (s)	−461	−401	88
Cu ₂ O(s)	−168.6	−146.0	93.1	Manganese			
CuO(s)	−157.3	−130	42.63	Mn(s, α)	0	0	31.8
Cu ₂ S(s)	−79.5	−86.2	120.9	Mn ²⁺ (aq)	−219	−223	−84
CuS(s)	−53.1	−53.6	66.5	MnO ₂ (s)	−520.9	−466.1	53.1
Fluorine				MnO ₄ [−] (aq)	−518.4	−425.1	190
F ₂ (g)	0	0	202.7	Mercury			
F(g)	78.9	61.8	158.64	Hg(l)	0	0	76.027
F [−] (g)	−255.6	−262.5	145.47	Hg(g)	61.30	31.8	174.87
F [−] (aq)	−329.1	−276.5	−9.6	Hg ²⁺ (aq)	171	164.4	−32
HF(g)	−273	−275	173.67	Hg ₂ ²⁺ (aq)	172	153.6	84.5
Hydrogen				HgCl ₂ (s)	−230	−184	144
H ₂ (g)	0	0	130.6	Hg ₂ Cl ₂ (s)	−264.9	−210.66	196
H(g)	218.0	203.30	114.60	HgO(s)	−90.79	−58.50	70.27
H ⁺ (aq)	0	0	0	Nitrogen			
H ⁺ (g)	1536.3	1517.1	108.83	N ₂ (g)	0	0	191.5
Iodine				N(g)	473	456	153.2
I ₂ (s)	0	0	116.14	N ₂ O(g)	82.05	104.2	219.7
I ₂ (g)	62.442	19.38	260.58	NO(g)	90.29	86.60	210.65
I(g)	106.8	70.21	180.67	NO ₂ (g)	33.2	51	239.9
I [−] (g)	−194.7	—	—	N ₂ O ₄ (g)	9.16	97.7	304.3
I [−] (aq)	−55.94	−51.67	109.4	N ₂ O ₅ (g)	11	118	346
HI(g)	25.9	1.3	206.33	N ₂ O ₅ (s)	−43.1	114	178
Iron				NH ₃ (g)	−45.9	−16	193
Fe(s)	0	0	27.3	NH ₃ (aq)	−80.83	26.7	110
Fe ³⁺ (aq)	−47.7	−10.5	−293	N ₂ H ₄ (l)	50.63	149.2	121.2

(continued)

Substance or Ion	ΔH_f° (kJ/mol)	ΔG_f° (kJ/mol)	S° (J/mol·K)	Substance or Ion	ΔH_f° (kJ/mol)	ΔG_f° (kJ/mol)	S° (J/mol·K)
$\text{NO}_3^-(aq)$	−206.57	−110.5	146	$\text{AgF}(s)$	−203	−185	84
$\text{HNO}_3(l)$	−173.23	−79.914	155.6	$\text{AgCl}(s)$	−127.03	−109.72	96.11
$\text{HNO}_3(aq)$	−206.57	−110.5	146	$\text{AgBr}(s)$	−99.51	−95.939	107.1
$\text{NF}_3(g)$	−125	−83.3	260.6	$\text{AgI}(s)$	−62.38	−66.32	114
$\text{NOCl}(g)$	51.71	66.07	261.6	$\text{AgNO}_3(s)$	−45.06	19.1	128.2
$\text{NH}_4\text{Cl}(s)$	−314.4	−203.0	94.6	$\text{Ag}_2\text{S}(s)$	−31.8	−40.3	146
Oxygen				Sodium			
$\text{O}_2(g)$	0	0	205.0	$\text{Na}(s)$	0	0	51.446
$\text{O}(g)$	249.2	231.7	160.95	$\text{Na}(g)$	107.76	77.299	153.61
$\text{O}_3(g)$	143	163	238.82	$\text{Na}^+(g)$	609.839	574.877	147.85
$\text{OH}^-(aq)$	−229.94	−157.30	−10.54	$\text{Na}^+(aq)$	−239.66	−261.87	60.2
$\text{H}_2\text{O}(g)$	−241.826	−228.60	188.72	$\text{NaF}(s)$	−575.4	−545.1	51.21
$\text{H}_2\text{O}(l)$	−285.840	−237.192	69.940	$\text{NaCl}(s)$	−411.1	−384.0	72.12
$\text{H}_2\text{O}_2(l)$	−187.8	−120.4	110	$\text{NaBr}(s)$	−361	−349	86.82
$\text{H}_2\text{O}_2(aq)$	−191.2	−134.1	144	$\text{NaOH}(s)$	−425.609	−379.53	64.454
Phosphorus				$\text{Na}_2\text{CO}_3(s)$	−1130.8	−1048.1	139
$\text{P}_4(s, \text{white})$	0	0	41.1	$\text{NaHCO}_3(s)$	−947.7	−851.9	102
$\text{P}(g)$	314.6	278.3	163.1	$\text{NaI}(s)$	−288	−285	98.5
$\text{P}(s, \text{red})$	−17.6	−12.1	22.8	Strontium			
$\text{P}_2(g)$	144	104	218	$\text{Sr}(s)$	0	0	54.4
$\text{P}_4(g)$	58.9	24.5	280	$\text{Sr}(g)$	164	110	164.54
$\text{PCl}_3(g)$	−287	−268	312	$\text{Sr}^{2+}(g)$	1784	—	—
$\text{PCl}_3(l)$	−320	−272	217	$\text{Sr}^{2+}(aq)$	−545.51	−557.3	−39
$\text{PCl}_5(g)$	−402	−323	353	$\text{SrCl}_2(s)$	−828.4	−781.2	117
$\text{PCl}_5(s)$	−443.5	—	—	$\text{SrCO}_3(s)$	−1218	−1138	97.1
$\text{P}_4\text{O}_{10}(s)$	−2984	−2698	229	$\text{SrO}(s)$	−592.0	−562.4	55.5
$\text{PO}_4^{3-}(aq)$	−1266	−1013	−218	$\text{SrSO}_4(s)$	−1445	−1334	122
$\text{HPO}_4^{2-}(aq)$	−1281	−1082	−36	Sulfur			
$\text{H}_2\text{PO}_4^-(aq)$	−1285	−1135	89.1	$\text{S}(\text{rhombic})$	0	0	31.9
$\text{H}_3\text{PO}_4(aq)$	−1277	−1019	228	$\text{S}(\text{monoclinic})$	0.3	0.096	32.6
Potassium				$\text{S}(g)$	279	239	168
$\text{K}(s)$	0	0	64.672	$\text{S}_2(g)$	129	80.1	228.1
$\text{K}(g)$	89.2	60.7	160.23	$\text{S}_8(g)$	101	49.1	430.211
$\text{K}^+(g)$	514.197	481.202	154.47	$\text{S}^{2-}(aq)$	41.8	83.7	22
$\text{K}^+(aq)$	−251.2	−282.28	103	$\text{HS}^-(aq)$	−17.7	12.6	61.1
$\text{KF}(s)$	−568.6	−538.9	66.55	$\text{H}_2\text{S}(g)$	−20.2	−33	205.6
$\text{KCl}(s)$	−436.7	−409.2	82.59	$\text{H}_2\text{S}(aq)$	−39	−27.4	122
$\text{KBr}(s)$	−394	−380	95.94	$\text{SO}_2(g)$	−296.8	−300.2	248.1
$\text{KI}(s)$	−328	−323	106.39	$\text{SO}_3(g)$	−396	−371	256.66
$\text{KOH}(s)$	−424.8	−379.1	78.87	$\text{SO}_4^{2-}(aq)$	−907.51	−741.99	17
$\text{KClO}_3(s)$	−397.7	−296.3	143.1	$\text{HSO}_4^-(aq)$	−885.75	−752.87	126.9
$\text{KClO}_4(s)$	−432.75	−303.2	151.0	$\text{H}_2\text{SO}_4(l)$	−813.989	−690.059	156.90
Rubidium				$\text{H}_2\text{SO}_4(aq)$	−907.51	−741.99	17
$\text{Rb}(s)$	0	0	69.5	Tin			
$\text{Rb}(g)$	85.81	55.86	169.99	$\text{Sn}(\text{white})$	0	0	51.5
$\text{Rb}^+(g)$	495.04	—	—	$\text{Sn}(\text{gray})$	3	4.6	44.8
$\text{Rb}^+(aq)$	−246	−282.2	124	$\text{SnCl}_4(l)$	−545.2	−474.0	259
$\text{RbF}(s)$	−549.28	—	—	$\text{SnO}_2(s)$	−580.7	−519.7	52.3
$\text{RbCl}(s)$	−435.35	−407.8	95.90	Titanium			
$\text{RbBr}(s)$	−389.2	−378.1	108.3	$\text{Ti}(s)$	0	0	30.7
$\text{RbI}(s)$	−328	−326	118.0	$\text{TiCl}_4(l)$	−804.2	−737.2	252.3
Silicon				$\text{TiO}_2(s)$	−944.0	−888.8	50.6
$\text{Si}(s)$	0	0	18.0	Zinc			
$\text{SiF}_4(g)$	−1614.9	−1572.7	282.4	$\text{Zn}(s)$	0	0	41.6
$\text{SiO}_2(s)$	−910.9	−856.5	41.5	$\text{Zn}(g)$	130.5	94.93	160.9
Silver				$\text{Zn}^{2+}(aq)$	−152.4	−147.21	−106.5
$\text{Ag}(s)$	0	0	42.702	$\text{ZnO}(s)$	−348.0	−318.2	43.9
$\text{Ag}(g)$	289.2	250.4	172.892	$\text{ZnS}(s, \text{zinc blende})$	−203	−198	57.7
$\text{Ag}^+(aq)$	105.9	77.111	73.93				