

# Thermodynamic Properties of Selected Substances

For one mole at 298K and 1 atmosphere pressure

Substance (form)	Enthalpy $\Delta H_f^\circ$ (kJ)	Gibbs $\Delta G_f^\circ$ (kJ)	Entropy $S^\circ$ (J/K)	Specific heat $C_p$ (J/K)	Volume $V$ (cm <sup>3</sup> )
Al (s)	0	0	28.33	24.35	9.99
Al <sub>2</sub> SiO <sub>5</sub> (kyanite)	-2594.3	-2443.88	83.81	121.71	44.09
Al <sub>2</sub> SiO <sub>5</sub> (andalusite)	-2590.3	-2442.66	93.22	122.72	51.53
Al <sub>2</sub> SiO <sub>5</sub> (sillimanite)	-2587.8	-2440.99	96.11	124.52	49.90
Ar (g)	0	0	154.84	20.79	...
C (graphite)	0	0	5.74	8.53	5.30
Ba(s)	0	0	63.2		
BaCO <sub>3</sub> (s)	-1216.3	-1137.6	112.1		
BaO(s)	-553.5	-525.1	70.42		
Br(g)	111.8	82.38	174.9		
Br <sup>-</sup> (aq)	-120.9	-102.8	80.71		
Br <sub>2</sub> (g)	30.71	3.14	245.3		
Br <sub>2</sub> (l)	0	0	152.3		
C (diamond)	1.895	2.900	2.38	6.11	3.42
C(graphite)	0	0	5.69		
CO (g)	-110.53	-137.17	197.67	29.14	...
CO <sub>2</sub> (g)	-393.51	-394.36	213.74	37.11	...
Ca(s)	0	0	41.4	...	...
Ca(g)	179.3	145.5	154.8		
Ca <sup>2+</sup> (aq)	-542.83	-553.58	-53.1		
CaCO <sub>3</sub> (calcite)	-1206.9	-1128.8	92.9	81.88	36.93
CaCO <sub>3</sub> (aragonite)	-1207.1	-1127.8	88.7	81.25	34.15
CaCl <sub>2</sub> (s)	-795.8	-748.1	104.6	72.59	51.6
CaF <sub>2</sub> (s)	-1219.6	-1167.3	68.87		
CaO(s)	-635.5	-604.17	39.75		
Ca(OH) <sub>2</sub> (s)	-986.2	-898.5	83.4		...
CaSO <sub>4</sub> (s)	-1434.0	-1321.8	106.7		
Cl <sub>2</sub> (g)	0	0	223.07	33.91	
Cl (g)	127.7	105.7	165.2		
Cl <sup>-</sup> (aq)	-167.16	-131.23	56.5	-136.4	17.3
Co(s)	0	0	28.4		
Co(g)	439	393	179		
Cr(s)	0	0	23.6		
Cr(g)	397.5	352.6	174.2		
Cr <sub>2</sub> O <sub>3</sub> (s)	-1139.7	-1058.1	81.2		
Cu (s)	0	0	33.150	24.44	7.12
Cu(g)	338.4	298.6	166.3		

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F (g)	80.0	61.9	158.7		
F <sub>2</sub> (g)	0	0	202.7		
Fe (s)	0	0	27.28	25.10	7.11
Fe <sup>2+</sup> (aq)	-87.86	-84.93	113.4		
Fe <sup>3+</sup> (aq)	-47.69	-10.54	293.3		
FeCl <sub>3</sub> (s)	-400	-334	142.3		
FeO(s)	-271.9	-255.2	60.75		
Fe <sub>2</sub> O <sub>3</sub> (s)	-822.16	-740.98	89.96		
Fe <sub>3</sub> O <sub>4</sub> (s)	-1117.1	-1014.2	146.4		
H <sub>2</sub> (g)	0	0	130.68	28.82	...
H (g)	217.97	203.25	114.71	20.78	...
H <sup>+</sup> (aq)	0	0	0	0	...
HBr(g)	-36.23	-53.22	198.49		
HCl(g)	-92.3	-95.27	186.69		
HF(g)	-268.61	-270.70	173.51		
HI(g)	25.94	1.30	206.3		
HNO <sub>3</sub> (aq)	-206.6	-110.5	146		
H <sub>2</sub> Se(g)	29.7	15.9	219		
H <sub>2</sub> S(g)	-20.17	33.01	205.6		
H <sub>2</sub> CO <sub>3</sub> (aq)	-699.65	-623.08	187.4	...	...
HCO <sub>3</sub> <sup>-</sup> (aq)	-691.99	-586.77	91.2	...	...
HSO <sub>4</sub> <sup>-</sup> (aq)	-887.34	-755.91	131.8	-84	...
H <sub>4</sub> SiO <sub>4</sub> (aq)	-1449.4	-1307.7	215.13	468.98	...
H <sub>2</sub> O (l)	-285.83	-237.13	69.91	75.29	18.068
H <sub>2</sub> O (g)	-241.82	-228.57	188.83	33.58	...
H <sub>2</sub> O <sub>2</sub> (l)	-187.8	-120.4	109.6		
He (g)	0	0	126.15	20.79	...
Hg (l)	0	0	76.02	27.98	14.81
N <sub>2</sub> (g)	0	0	191.61	29.12	...
NH <sub>3</sub> (g)	-46.11	-16.45	192.45	35.06	...
Na <sup>+</sup> (aq)	-240.12	-261.91	59.0	46.4	-1.2
NaCl (s)	-411.15	-384.14	72.13	50.50	27.01
Ne (g)	0	0	146.33	20.79	...
O <sub>2</sub> (g)	0	0	205.14	29.38	...
O <sub>2</sub> (aq)	-11.7	16.4	110.9	...	...
OH <sup>-</sup> (aq)	-229.99	-157.24	-10.75	-148.5	...
Pb (s)	0	0	64.81	26.44	18.3
PbO <sub>2</sub> (s)	-277.4	-217.33	68.6	64.64	...
PbSO <sub>4</sub> (s)	-920.0	-813.0	148.5	103.2	...
SO <sub>4</sub> <sup>2-</sup> (aq)	-909.27	-744.53	20.1	-293	...
SiO <sub>2</sub> (a quartz)	-910.94	-856.64	41.84	44.43	22.69

Organics					
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CH <sub>4</sub> (g)	-74.81	-50.72	186.26	35.31	...
CCl <sub>4</sub> (g)	-106.7	-64.0	309.4		
CCl <sub>4</sub> (l)	-139.3	-68.6	214.4		
CF <sub>4</sub> (g)	-679.9	-635.1	262.3		
CH <sub>3</sub> OH(g)	-201.2	-161.9	237.6		
CH <sub>3</sub> OH(l)	-238.6	-166.23	126.8		
HCHO(g)	-116	-110	219		
HCOOH(aq)	-410	-356	164		
C <sub>2</sub> H <sub>2</sub> (g)	226.7	209.2	200.8		
C <sub>2</sub> H <sub>4</sub> (g)	52.3	68.11	219.4		
CH <sub>3</sub> COOH(l)	-487.0	-392.4	159.8		

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C <sub>2</sub> H <sub>6</sub> (g)	-84.68	-32.82	229.60	52.63	...
C <sub>2</sub> H <sub>5</sub> OH (l)	-277.69	-174.78	160.7	111.46	58.4
CH <sub>3</sub> CHO(g)	-166	-133.7	266		
CH <sub>3</sub> COCH <sub>3</sub> (l)	-248.1	-155.4	200.4		
C <sub>3</sub> H <sub>8</sub> (g)	-103.85	-23.49	269.91	73.5	...
C <sub>4</sub> H <sub>10</sub> (g)	-126	-17	310.2		
C <sub>6</sub> H <sub>6</sub> (l)	49.0	124.5	172.8		
C <sub>6</sub> H <sub>6</sub> (g)	82.9	129.7	269.2		
C <sub>6</sub> H <sub>5</sub> COOH(s)	-385.1	-245.3	167.6	-245.3	
C <sub>6</sub> H <sub>12</sub> O <sub>6</sub> (glucose)	-1268	-910	212	115	...

### Average Bond Dissociation Energies

Single Bonds (kJ/mol)									
	H	C	N	O	S	F	Cl	Br	I
H	432								
C	411	346							
N	386	305	167						
O	459	358	201	142					
S	363	272	-	-	226				
F	565	485	283	190	284	155			
Cl	428	327	313	218	255	249	240		
Br	362	285	-	201	217	249	216	190	
I	295	213	-	201	-	278	208	175	149
Multiple Bonds									
C=C	602		C=N	615		C=O	799		
C≡C	835		C≡N	887		C≡O	1072		
N=N	418		N=O	607		S=O	532*		
N≡N	942		O=O	494					

\*Bond energy for S=O bond from the SO<sub>2</sub> resonance structure.