TABLE 2-178 Heats and Free Energies of Formation of Inorganic Compounds

The values given in the following table for the heats and free energies of formation of inorganic compounds are derived from (*a*) Bichowsky and Rossini, "Thermochemistry of the Chemical Substances," Reinhold, New York, 1936; (*b*) Latimer, "Oxidation States of the Elements and Their Potentials in Aqueous Solution," Prentice-Hall, New York, 1938; (*c*) the tables of the American Petroleum Institute Research Project 44 at the National Bureau of Standards; and (*d*) the tables of Selected Values of Chemical Thermodynamic Properties of the National Bureau of Standards. The reader is referred to the preceding books and tables for additional details as to methods of calculation, standard states, and so on.

Compound	State†	Heat of formation‡§ ΔH (formation) at 25 °C, kcal/mol	Free energy of formation‖¶ ΔF (formation) at 25 °C, kcal/mol
Aluminum			
Al	c	0.00	0.00
$AlBr_3$	c	−123.4	
	aq	−209.5	−189.2
Al_4C_3	c	−30.8	−29.0
$AlCl_3$	c	−163.8	
	aq, 600	−243.9	−209.5
AlF_3	c	−329	
	aq	−360.8	−312.6
AlI_3	c	−72.8	
	aq	−163.4	−152.5
AlN	c	−57.7	−50.4
$Al(NH_4)(SO_4)_2$	c	−561.19	−486.17
$Al(NH_4)(SO_4)_2{\cdot}12H_2O$	c	−1419.36	−1179.26
$Al(NO_3)_3{\cdot}6H_2O$	c	−680.89	−526.32
$Al(NO_3)_3{\cdot}9H_2O$	c	−897.59	
Al_2O_3	c, corundum	−399.09	−376.87
$Al(OH)_3$	c	−304.8	−272.9
$Al_2O_3{\cdot}SiO_2$	c, sillimanite	−648.7	
$Al_2O_3{\cdot}SiO_2$	c, disthene	−642.4	
$Al_2O_3{\cdot}SiO_2$	c, andalusite	−642.0	
$3Al_2O_3{\cdot}2SiO_2$	c, mullite	−1874	
Al_2S_3	c	−121.6	
$Al_2(SO_4)_3$	c	−820.99	−739.53
	aq	−893.9	−759.3
$Al_2(SO_4)_3{\cdot}6H_2O$	c	−1268.15	−1103.39
$Al_2(SO_4)_3{\cdot}18H_2O$	c	−2120	
Antimony			
Sb	c	0.00	0.00
$SbBr_3$	c	−59.9	
$SbCl_3$	c	−91.3	−77.8
$SbCl_5$	l	−104.8	
SbF_3	c	−216.6	
SbI_3	c	−22.8	
Sb_2O_3	c, I, orthorhombic	−165.4	−146.0
	c, II, octahedral	−166.6	
Sb_2O_4	c	−213.0	−186.6
Sb_2O_5	c	−230.0	−196.1
Sb_2S_3	c, black	−38.2	−36.9
Arsenic			
As	c	0.00	0.00
$AsBr_3$	c	−45.9	
$AsCl_3$	l	−80.2	−70.5
AsF_3	l	−223.76	−212.27
AsH_3	g	43.6	37.7
AsI_3	c	−13.6	
As_2O_3	c	−154.1	−134.8
As_2O_5	c	−217.9	−183.9
As_2S_3	c	−20	−20
	amorphous	−34.76	
Barium			
Ba	c	0.00	0.00
$BaBr_2$	c	−180.38	
	aq, 400	−185.67	−183.0
$BaCl_2$	c	−205.25	
	aq, 300	−207.92	−196.5
$Ba(ClO_3)_2$	c	−176.6	
	aq, 1600	−170.0	−134.4
$Ba(ClO_4)_2$	c	−210.2	
	aq, 800		−155.3
$Ba(CN)_2$	c	−48	
$Ba(CNO)_2$	c	−212.1	
	aq		−180.7
$BaCN_2$	c	−63.6	
$BaCO_3$	c, witherite	−284.2	−271.4
$BaCrO_4$	c	−342.2	
Barium (*Cont.*)			
BaF_2	c	−287.9	
	aq, 1600	−284.6	−265.3
BaH_2	c	−40.8	−31.5
$Ba(HCO_3)_2$	aq	−459	−414.4
BaI_2	c	−144.6	
	aq, 400	−155.17	−158.52
$Ba(IO_3)_2$	c	−264.5	
	aq	−237.50	−198.35
$BaMoO_4$	c	−370	
Ba_3N_2	c	−90.7	
$Ba(NO_2)_2$	c	−184.5	
	aq	−179.05	−150.75
$Ba(NO_3)_2$	c	−236.99	−189.94
	aq, 600	−227.74	
BaO	c	−133.0	
$Ba(OH)_2$	c	−225.9	
	aq, 400	−237.76	−209.02
$BaO{\cdot}SiO_2$	c	−363	
$Ba_3(PO_4)_2$	c	−992	
$BaPtCl_6$	c	−284.9	
BaS	c	−111.2	
$BaSO_3$	c	−282.5	
$BaSO_4$	c	−340.2	−313.4
$BaWO_4$	c	−402	
Beryllium			
Be	c	0.00	0.00
$BeBr_2$	c	−79.4	
	aq	−142	−127.9
$BeCl_2$	c	−112.6	
	aq	−163.9	−141.4
BeI_2	c	−39.4	
	aq	−112	−103.4
Be_3N_2	c	−134.5	−122.4
BeO	c	−145.3	−138.3
$Be(OH)_2$	c	−215.6	
BeS	c	−56.1	
$BeSO_4$	c	−281	
	aq		−254.8
Bismuth			
Bi	c	0.00	0.00
$BiCl_3$	c	−90.5	−76.4
	aq	−101.6	
BiI_3	c	−24	
	aq	−27	
BiO	c	−49.5	−43.2
Bi_2O_3	c	−137.1	−117.9
$Bi(OH)_3$	c	−171.1	
Bi_2S_3	c	−43.9	−39.1
$Bi_2(SO_4)_3$	c	−607.1	
Boron			
B	c	0.00	0.00
BBr_3	l	−52.7	
	g	−44.6	−50.9
BCl_3	g	−94.5	−90.8
BF_3	g	−265.2	−261.0
B_2H_6	g	7.5	19.9
BN	c	−32.1	−27.2
B_2O_3	c	−302.0	−282.9
	gls	−297.6	−280.3
$B(OH)_3$	c	−260.0	−229.4
B_2S_3	c	−56.6	
Bromine			
Br_2	l	0.00	0.00
	g	7.47	0.931
BrCl	g	3.06	−0.63

*For footnotes see end of table.

TABLE 2-178 Heats and Free Energies of Formation of Inorganic Compounds (*Continued*)

Compound	State†	Heat of formation‡§ ΔH (formation) at 25 °C, kcal/mol	Free energy of formation‖¶ ΔF (formation) at 25 °C, kcal/mol
Cadmium			
Cd	c	0.00	0.00
$CdBr_2$	c	−75.8	−70.7
	aq, 400	−76.6	−67.6
$CdCl_2$	c	−92.149	−81.889
	aq, 400	−96.44	−81.2
$Cd(CN)_2$	c	36.2	
$CdCO_3$	c	−178.2	−163.2
CdI_2	c	−48.40	
	aq, 400	−47.46	−43.22
Cd_3N_2	c	39.8	
$Cd(NO_3)_2$	aq, 400	−115.67	−71.05
CdO	c	−62.35	−55.28
$Cd(OH)_2$	c	−135.0	−113.7
CdS	c	−34.5	−33.6
$CdSO_4$	c	−222.23	
	aq, 400	−232.635	−194.65
Calcium			
Ca	c	0.00	0.00
$CaBr_2$	c	−162.20	
	aq, 400	−187.19	−181.86
CaC_2	c	−14.8	−16.0
$CaCl_2$	c	−190.6	−179.8
	aq	−209.15	−195.36
$CaCN_2$	c	−85	
$Ca(CN)_2$	c	−43.3	
	aq		−54.0
$CaCO_3$	c, calcite	−289.5	−270.8
	c, aragonite	−289.54	−270.57
$CaCO_3{\cdot}MgCO_3$	c	−558.8	
CaC_2O_4	c	−332.2	
$Ca(C_2H_3O_2)_2$	c	−356.3	
	aq	−364.1	−311.3
CaF_2	c	−290.2	
	aq	−286.5	−264.1
CaH_2	c	−46	−35.7
CaI_2	c	−128.49	
	aq, 400	−156.63	−157.37
Ca_3N_2	c	−103.2	−88.2
$Ca(NO_3)_2$	c	−224.05	−177.38
	aq, 400	−228.29	
$Ca(NO_3)_2{\cdot}2H_2O$	c	−367.95	−293.57
$Ca(NO_3)_2{\cdot}3H_2O$	c	−439.05	−351.58
$Ca(NO_3)_2{\cdot}4H_2O$	c	−509.43	−409.32
CaO	c	−151.7	−144.3
$Ca(OH)_2$	c	−235.58	−213.9
	aq, 800	−239.2	−207.9
$CaO{\cdot}SiO_2$	c, II, wollastonite	−377.9	−357.5
	c, I, pseudo-wollastonite	−376.6	−356.6
CaS	c	−114.3	−113.1
$CaSO_4$	c, insoluble form	−338.73	−311.9
	c, soluble form α	−336.58	−309.8
	c, soluble form β	−335.52	−308.8
$CaSO_4{\cdot}½H_2O$	c	−376.13	
$CaSO_4{\cdot}2H_2O$	c	−479.33	−425.47
$CaWO_4$	c	−387	
Carbon			
C	c, graphite	0.00	0.00
	c, diamond	0.453	0.685
CO	g	−26.416	−32.808
CO_2	g	−94.052	−94.260
Cerium			
Ce	c	0.00	0.00
CeN	c	−78.2	−70.8
Cesium			
Cs	c	0.00	0.00
CsBr	c	−97.64	
	aq, 500	−91.39	−94.86
CsCl	c	−106.31	
	aq, 400	−102.01	−101.61
Cesium (*Cont.*)			
Cs_2CO_3	c	−271.88	
CsF	c	−131.67	
	aq, 400	−140.48	−135.98
CsH	c	−12	−7.30
$CsHCO_3$	c	−230.6	
	aq, 2000	−226.6	−210.56
CsI	c	−83.91	
	aq, 400	−75.74	−82.61
$CsNH_2$	c	−28.2	
$CsNO_3$	c	−121.14	
	aq, 400	−111.54	−96.53
Cs_2O	c	−82.1	
CsOH	c	−100.2	
	aq, 200	−117.0	−107.87
Cs_2S	c	−87	
Cs_2SO_4	c	−344.86	
	aq	−340.12	−316.66
Chlorine			
Cl_2	g	0.00	0.00
ClF	g	−25.7	
ClO	g	33	
ClO_2	g	24.7	29.5
ClO_3	g	37	
Cl_2O	g	18.20	22.40
Cl_2O_7	g	63	
Chromium			
Cr	c	0.00	0.00
$CrBr_3$	aq		−122.7
Cr_3C_2	c	−21.008	−21.20
Cr_4C	c	−16.378	−16.74
$CrCl_2$	c	−103.1	−93.8
	aq		−102.1
CrF_2	c	−152	
CrF_3	c	−231	
CrI_2	c	−63.7	
	aq		−64.1
CrO_3	c	−139.3	
Cr_2O_3	c	−268.8	−249.3
$Cr_2(SO_4)_3$	aq		−626.3
Cobalt			
Co	c	0.00	0.00
$CoBr_2$	c	−55.0	
	aq	−73.61	−61.96
Co_3C	c	9.49	7.08
$CoCl_2$	c	−76.9	−66.6
	aq, 400	−95.58	−75.46
$CoCO_3$	c	−172.39	−155.36
CoF_2	aq	−172.98	−144.2
CoI_2	c	−24.2	
	aq	−43.15	−37.4
$Co(NO_3)_2$	c	−102.8	
	aq	−114.9	−65.3
CoO	c	−57.5	
Co_3O_4	c	−196.5	
$Co(OH)_2$	c	−131.5	−108.9
$Co(OH)_3$	c	−177.0	−142.0
CoS	c	−22.3	−19.8
Co_2S_3	c	−40.0	
$CoSO_4$	c	−216.6	
	aq, 400		−188.9
Columbium			
Cb	c	0.00	0.00
Cb_2O_5	c	−462.96	
Copper			
Cu	c	0.00	0.00
CuBr	c	−26.7	−23.8
$CuBr_2$	c	−34.0	
	aq	−42.4	−33.25
CuCl	c	−31.4	−24.13
$CuCl_2$	c	−48.83	
	aq, 400	−64.7	

TABLE 2-178 Heats and Free Energies of Formation of Inorganic Compounds (*Continued*)

Compound	State†	Heat of formation‡§ ΔH (formation) at 25 °C, kcal/mol	Free energy of formation‖¶ ΔF (formation) at 25 °C, kcal/mol
Copper (*Cont.*)			
$CuClO_4$	aq	−28.3	1.34
$Cu(ClO_3)_2$	aq, 400		15.4
$Cu(ClO_4)_2$	aq		−5.5
CuI	c	−17.8	−16.66
CuI_2	c	−4.8	
	aq	−11.9	−8.76
Cu_3N	c	17.78	
$Cu(NO_3)_2$	c	−73.1	
	aq, 200	−83.6	−36.6
CuO	c	−38.5	−31.9
Cu_2O	c	−43.00	−38.13
$Cu(OH)_2$	c	−108.9	−85.5
CuS	c	−11.6	−11.69
Cu_2S	c	−18.97	−20.56
$CuSO_4$	c	−184.7	−158.3
	aq, 800	−200.78	−160.19
Cu_2SO_4	c	−179.6	
	aq		−152.0
Erbium			
Er	c	0.00	0.00
$Er(OH)_3$	c	−326.8	
Fluorine			
F_2	g	0.00	0.00
F_2O	g	5.5	9.7
Gallium			
Ga	c	0.00	0.00
$GaBr_3$	c	−92.4	
$GaCl_3$	c	−125.4	
GaN	c	−26.2	
Ga_2O	c	−84.3	
Ga_2O_3	c	−259.9	
Germanium			
Ge	c	0.00	0.00
Ge_3N_4	c	−15.7	
GeO_2	c	−128.6	
Gold			
Au	c	0.00	0.00
AuBr	c	−3.4	
$AuBr_3$	c	−14.5	
	aq	−11.0	24.47
AuCl	c	−8.3	
$AuCl_3$	c	−28.3	
	aq	−32.96	4.21
AuI	c	0.2	−0.76
Au_2O_3	c	11.0	18.71
$Au(OH)_3$	c	−100.6	
Hafnium			
Hf	c	0.00	0.00
HfO_2	c	−271.1	−258.2
Hydrogen			
H_3AsO_3	aq	−175.6	−153.04
H_3AsO_4	c	−214.9	
	aq	−214.8	−183.93
HBr	g	−8.66	−12.72
	aq, 400	−28.80	−24.58
HBrO	aq	−25.4	−19.90
$HBrO_3$	aq	−11.51	5.00
HCl	g	−22.063	−22.778
	aq, 400	−39.85	−31.330
HCN	g	31.1	27.94
	aq, 100	24.2	26.55
HClO	aq, 400	−28.18	−19.11
$HClO_3$	aq	−23.4	−0.25
$HClO_4$	aq, 660	−31.4	−10.70
$HC_2H_3O_2$	l	−116.2	−93.56
	aq, 400	−116.74	−96.8
$H_2C_2O_4$	c	−196.7	
	aq, 300	−194.6	−165.64
HCOOH	l	−97.8	−82.7
	aq, 200	−98.0	−85.1
Hydrogen (*Cont.*)			
H_2CO_3	aq	−167.19	−149.0
HF	g	−64.2	−64.7
	aq, 200	−75.75	
HI	g	6.27	0.365
	aq, 400	−13.47	−12.35
HIO	aq	−38	−23.33
HIO_3	c	−56.77	
	aq	−54.8	−32.25
HN_3	g	70.3	78.50
HNO_3	g	−31.99	−17.57
	l	−41.35	−19.05
	aq, 400	−49.210	
$HNO_3 \cdot H_2O$	l	−112.91	−78.36
$HNO_3 \cdot 3H_2O$	l	−252.15	−193.70
H_2O	g	−57.7979	−54.6351
	l	−68.3174	−56.6899
H_2O_2	l	−45.16	−28.23
	aq, 200	−45.80	−31.47
H_3PO_2	c	−145.5	
	aq	−145.6	−120.0
H_3PO_3	c	−232.2	
	aq	−232.2	−204.0
H_3PO_4	c	−306.2	
	aq, 400	−309.32	−270.0
H_2S	g	−4.77	−7.85
	aq, 2000	−9.38	
H_2S_2	l	−3.6	
H_2SO_3	aq, 200	−146.88	−128.54
H_2SO_4	l	−193.69	
	aq, 400	−212.03	
H_2Se	g	20.5	17.0
	aq	18.1	18.4
H_2SeO_3	c	−126.5	
	aq	−122.4	−101.36
H_2SeO_4	c	−130.23	
	aq, 400	−143.4	
H_2SiO_3	c	−267.8	−247.9
H_4SiO_4	c	−340.6	
H_2Te	g	36.9	33.1
H_2TeO_3	c	−145.0	−115.7
	aq	−145.0	
H_2TeO_4	aq	−165.6	
Indium			
In	c	0.00	0.00
$InBr_3$	c	−97.2	
	aq	−112.9	−97.2
$InCl_3$	c	−128.5	
	aq	−145.6	−117.5
InI_3	c	−56.5	
	aq	−67.2	−60.5
InN	c	−4.8	
In_2O_3	c	−222.47	
Iodine			
I_2	c	0.00	0.00
	g	14.88	4.63
IBr	g	10.05	1.24
ICl	g	4.20	−1.32
ICl_3	c	−21.8	−6.05
I_2O_5	c	−42.5	
Iridium			
Ir	c	0.00	0.00
IrCl	c	−20.5	−16.9
$IrCl_2$	c	−40.6	−32.0
$IrCl_3$	c	−60.5	−46.5
IrF_6	l	−130	
IrO_2	c	−40.14	
Iron			
Fe	c, α	0.00	0.00
$FeBr_2$	c	−57.15	
	aq, 540	−78.7	−69.47

TABLE 2-178 Heats and Free Energies of Formation of Inorganic Compounds (*Continued*)

Compound	State†	Heat of formation‡§ ΔH (formation) at 25 °C, kcal/mol	Free energy of formation‖¶ ΔF (formation) at 25 °C, kcal/mol
Iron (*Cont.*)			
$FeBr_3$	aq	−95.5	−76.26
Fe_3C	c	5.69	4.24
$Fe(CO)_5$	l	−187.6	
$FeCO_3$	c, siderite	−172.4	−154.8
$FeCl_2$	c	−81.9	−72.6
	aq	−100.0	−83.0
$FeCl_3$	c	−96.4	
	aq, 2000	−128.5	−96.5
FeF_2	aq, 1200	−177.2	−151.7
FeI_2	c	−24.2	
	aq	−47.7	−45
FeI_3	aq	−49.7	−39.5
Fe_4N	c	−2.55	0.862
$Fe(NO_3)_2$	aq	−118.9	−72.8
$Fe(NO_3)_3$	aq, 800	−156.5	−81.3
FeO	c	−64.62	−59.38
Fe_2O_3	c	−198.5	−179.1
Fe_3O_4	c	−266.9	−242.3
$Fe(OH)_2$	c	−135.9	−115.7
$Fe(OH)_3$	c	−197.3	−166.3
$FeO{\cdot}SiO_2$	c	−273.5	
Fe_2P	c	−13	
FeSi	c	−19.0	
FeS	c	−22.64	−23.23
FeS_2	c, pyrites	−38.62	−35.93
	c, marcasite	−33.0	
$FeSO_4$	c	−221.3	−195.5
	aq, 400	−236.2	−196.4
$Fe_2(SO_4)_3$	aq, 400	−653.3	−533.4
$FeTiO_3$	c, ilmenite	−295.51	−277.06
Lanthanum			
La	c	0.00	0.00
$LaCl_3$	c	−253.1	
	aq	−284.7	
La_3H_8	c	−160	
LaN	c	−72.0	−64.6
La_2O_3	c	−539	
LaS_2	c	−148.3	
La_2S_3	c	−351.4	
$La_2(SO_4)_3$	aq	−972	
Lead			
Pb	c	0.00	0.00
$PbBr_2$	c	−66.24	−62.06
	aq	−56.4	−54.97
$PbCO_3$	c, cerussite	−167.6	−150.0
$Pb(C_2H_3O_2)_2$	c	−232.6	
	aq, 400	−234.2	−184.40
PbC_2O_4	c	−205.3	
$PbCl_2$	c	−85.68	−75.04
	aq	−82.5	−68.47
PbF_2	c	−159.5	−148.1
PbI_2	c	−41.77	−41.47
$Pb(NO_3)_2$	c	−106.88	
	aq, 400	−99.46	−58.3
PbO	c, red	−51.72	−45.53
	c, yellow	−50.86	−43.88
PbO_2	c	−65.0	−52.0
Pb_3O_4	c	−172.4	−142.2
$Pb(OH)_2$	c	−123.0	−102.2
PbS	c	−22.38	−21.98
$PbSO_4$	c	−218.5	−192.9
Lithium			
Li	c	0.00	0.00
LiBr	c	−83.75	
	aq, 400	−95.40	−95.28
$LiBrO_3$	aq	−77.9	−65.70
Li_2C_2	c	−13.0	
LiCN	aq	−31.4	−31.35
LiCNO	aq	−101.2	−94.12
Lithium (*Cont.*)			
$LiC_2H_3O_2$	aq	−183.9	−160.00
Li_2CO_3	c	−289.7	−269.8
	aq, 1900	−293.1	−267.58
LiCl	c	−97.63	
	aq, 278	−106.45	−102.03
$LiClO_3$	aq	−87.5	−70.95
$LiClO_4$	aq	−106.3	−81.4
LiF	c	−145.57	
	aq, 400	−144.85	−136.40
LiH	c	−22.9	
$LiHCO_3$	aq, 2000	−231.1	−210.98
LiI	c	−65.07	
	aq, 400	−80.09	−83.03
$LiIO_3$	aq	−121.3	−102.95
Li_3N	c	−47.45	−37.33
$LiNO_3$	c	−115.350	
	aq, 400	−115.88	−96.95
Li_2O	c	−142.3	
Li_2O_2	c	−151.9	−138.0
	aq	−159	
LiOH	c	−116.58	−106.44
	aq, 400	−121.47	−108.29
$LiOH{\cdot}H_2O$	c	−188.92	
$Li_2O{\cdot}SiO_2$	gls	−374	
Li_2Se	c	−84.9	
	aq	−95.5	−105.64
Li_2SO_4	c	−340.23	−314.66
	aq, 400	−347.02	
$Li_2SO_4{\cdot}H_2O$	c	−411.57	−375.07
Magnesium			
Mg	c	0.00	0.00
$Mg(AsO_4)_2$	c	−731.3	
	aq	−749	−630.14
$MgBr_2$	c	−123.9	
	aq, 400	−167.33	−156.94
$Mg(CN)_2$	aq	−39.7	−29.08
$MgCN_2$	c	−61	
$Mg(C_2H_3O_2)_2$	aq	−344.6	−286.38
$MgCO_3$	c	−261.7	−241.7
$MgCl_2$	c	−153.220	−143.77
	aq, 400	−189.76	
$MgCl_2{\cdot}H_2O$	c	−230.970	−205.93
$MgCl_2{\cdot}2H_2O$	c	−305.810	−267.20
$MgCl_2{\cdot}4H_2O$	c	−453.820	−387.98
$MgCl_2{\cdot}6H_2O$	c	−597.240	−505.45
MgF_2	c	−263.8	
MgI_2	c	−86.8	
	aq, 400	−136.79	−132.45
$MgMoO_4$	c	−329.9	
Mg_3N_2	c	−115.2	−100.8
$Mg(NO_3)_2$	c	−188.770	−140.66
	aq, 400	−209.927	−160.28
$Mg(NO_3)_2{\cdot}2H_2O$	c	−336.625	
$Mg(NO_3)_2{\cdot}6H_2O$	c	−624.48	−496.03
MgO	c	−143.84	−136.17
$MgO{\cdot}SiO_2$	c	−347.5	−326.7
$Mg(OH)_2$	c, ppt.	−221.90	−200.17
	c, brucite	−223.9	−193.3
MgS	c	−84.2	
	aq	−108	
$MgSO_4$	c	−304.94	−277.7
	aq, 400	−325.4	−283.88
MgTe	c	−25	
$MgWO_4$	c	−345.2	
Manganese			
Mn	c, α	0.00	0.00
$MnBr_2$	c	−91	
	aq	−106	−97.8
Mn_3C	c	1.1	1.26

TABLE 2-178 Heats and Free Energies of Formation of Inorganic Compounds (*Continued*)

Compound	State†	Heat of formation‡§ ΔH (formation) at 25 °C, kcal/mol	Free energy of formation‖¶ ΔF (formation) at 25 °C, kcal/mol
Manganese (*Cont.*)			
$Mn(C_2H_3O_2)_2$	c	−270.3	
	aq	−282.7	−227.2
$MnCO_3$	c	−211	−192.5
MnC_2O_4	c	−240.9	
$MnCl_2$	c	−112.0	−102.2
	aq, 400	−128.9	
MnF_2	aq, 1200	−206.1	−180.0
MnI_2	c	−49.8	
	aq	−76.2	−73.3
Mn_5N_2	c	−57.77	−46.49
$Mn(NO_3)_2$	c	−134.9	
	aq, 400	−148.0	−101.1
$Mn(NO_3)_2.6H_2O$	c	−557.07	−441.2
MnO	c	−92.04	−86.77
MnO_2	c	−124.58	−111.49
Mn_2O_3	c	−229.5	−209.9
Mn_3O_4	c	−331.65	−306.22
$MnO.SiO_2$	c	−301.3	−282.1
$Mn(OH)_2$	c	−163.4	−143.1
$Mn(OH)_3$	c	−221	−190
$Mn_3(PO_4)_2$	c	−736	
MnSe	c	−26.3	−27.5
MnS	c, green	−47.0	−48.0
$MnSO_4$	c	−254.18	−228.41
	aq, 400	−265.2	
$Mn_2(SO_4)_3$	c	−635	
	aq	−657	
Mercury			
Hg	l	0.00	0.00
HgBr	g	23	18
$HgBr_2$	c	−40.68	−38.8
	aq	−38.4	−9.74
$Hg(C_2H_3O_2)_2$	c	−196.3	
	aq	−192.5	−139.2
$HgCl_2$	c	−53.4	−42.2
	aq	−50.3	−23.25
HgCl	g	19	14
Hg_2Cl_2	c	−63.13	
$Hg(CN)_2$	c	62.8	
	aq, 1110	66.25	
HgC_2O_4	c	−159.3	
HgH	g	57.1	52.25
HgI_2	c, red	−25.3	−24.0
HgI	g	33	23
Hg_2I_2	c	−28.88	−26.53
$Hg(NO_3)_2$	aq	−56.8	−13.09
$Hg_2(NO_3)_2$	aq	−58.5	−15.65
HgO	c, red	−21.6	−13.94
	c, yellow ppt.	−20.8	
Hg_2O	c	−21.6	−12.80
HgS	c, black	−10.7	−8.80
$HgSO_4$	c	−166.6	
Hg_2SO_4	c	−177.34	−149.12
Molybdenum			
Mo	c	0.00	0.00
Mo_2C	c	4.36	2.91
Mo_2N	c	−8.3	
MoO_2	c	−130	−118.0
MoO_3	c	−180.39	−162.01
MoS_2	c	−56.27	−54.19
MoS_3	c	−61.48	−57.38
Nickel			
Ni	c	0.00	0.00
$NiBr_2$	c	−53.4	
	aq	−72.6	−60.7
Ni_3C	c	9.2	8.88
$Ni(C_2H_3O_2)_2$	aq	−249.6	−190.1
$Ni(CN)_2$	aq	230.9	66.3
$NiCl_2$	c	−75.0	
	aq, 400	−94.34	−74.19
NiF_2	c	−157.5	
	aq	−171.6	−142.9
NiI_2	c	−22.4	
	aq	−42.0	−36.2
$Ni(NO_3)_2$	c	−101.5	
	aq, 200	−113.5	−64.0
NiO	c	−58.4	−51.7
$Ni(OH)_2$	c	−129.8	−105.6
$Ni(OH)_3$	c	−163.2	
NiS	c	−20.4	
$NiSO_4$	c	−216	
	aq, 200	−231.3	−187.6
Nitrogen			
N_2	g	0.00	0.00
NF_3	g	−27	
NH_3	g	−10.96	−3.903
	aq, 200	−19.27	
NH_4Br	c	−64.57	
	aq	−60.27	−43.54
$NH_4C_2H_3O_2$	c	−148.1	
	aq, 400	−148.58	−108.26
NH_4CN	c	−0.7	
	aq	3.6	20.4
NH_4CNS	c	−17.8	
	aq	−12.3	4.4
$(NH_4)_2CO_3$	aq	−223.4	−164.1
$(NH_4)_2C_2O_4$	c	−266.3	
	aq	−260.6	−196.2
NH_4Cl	c	−75.23	−48.59
	aq, 400	−71.20	
NH_4ClO_4	c	−69.4	
	aq	−63.2	−21.1
$(NH_4)_2CrO_4$	c	−276.9	
	aq	−271.3	−209.3
NH_4F	c	−111.6	
	aq	−110.2	−84.7
NH_4I	c	−48.43	
	aq	−44.97	−31.3
NH_4NO_3	c	−87.40	
	aq, 500	−80.89	
NH_4OH	aq	−87.59	
$(NH_4)_2S$	aq, 400	−55.21	−14.50
$(NH_4)_2SO_4$	c	−281.74	−215.06
	aq, 400	−279.33	−214.02
N_2H_4	l	12.06	
$N_2H_4.H_2O$	l	−57.96	
$N_2H_4.H_2SO_4$	c	−232.2	
N_2O	g	19.55	24.82
NO	g	21.600	20.719
NO_2	g	7.96	12.26
N_2O_4	g	2.23	23.41
N_2O_5	c	−10.0	
NOBr	l	11.6	19.26
NOCl	g	12.8	16.1
Osmium			
Os	c	0.00	0.00
OsO_4	c	−93.6	−70.9
	g	−80.1	−68.1
Oxygen			
O_2	g	0.00	0.00
O_3	g	33.88	38.86
Palladium			
Pd	c	0.00	0.00
PdO	c	−20.40	
Phosphorus			
P	c, white (“yellow”)	0.00	0.00
	c, red (“violet”)	−4.22	−1.80
P	g	150.35	141.88

TABLE 2-178 Heats and Free Energies of Formation of Inorganic Compounds (*Continued*)

Compound	State†	Heat of formation‡§ ΔH (formation) at 25 °C, kcal/mol	Free energy of formation‖¶ ΔF (formation) at 25 °C, kcal/mol
Phosphorus (*Cont.*)			
P_2	g	33.82	24.60
P_4	g	13.2	5.89
PBr_3	l	−45	
PBr_5	c	−60.6	
PCl_3	g	−70.0	−65.2
	l	−76.8	−63.3
PCl_5	g	−91.0	−73.2
PH_3	g	2.21	−1.45
PI_3	c	−10.9	
P_2O_5	c	−360.0	
$POCl_3$	g	−138.4	−127.2
Platinum			
Pt	c	0.00	0.00
$PtBr_4$	c	−40.6	
	aq	−50.7	
$PtCl_2$	c	−34	
$PtCl_4$	c	−62.6	
	aq	−82.3	
PtI_4	c	−18	
$Pt(OH)_2$	c	−87.5	−67.9
PtS	c	−20.18	−18.55
PtS_2	c	−26.64	−24.28
Potassium			
K	c	0.00	0.00
K_3AsO_3	aq	−323.0	
K_3AsO_4	aq	−390.3	−355.7
KH_2AsO_4	c	−271.2	−236.7
KBr	c	−94.06	−90.8
	aq, 400	−89.19	−92.0
$KBrO_3$	c	−81.58	−60.30
	aq, 1667	−71.68	
$KC_2H_3O_2$	c	−173.80	
	aq, 400	−177.38	−156.73
KCl	c	−104.348	−97.76
	aq, 400	−100.164	−98.76
$KClO_3$	c	−93.5	−69.30
	aq, 400	−81.34	
$KClO_4$	c	−103.8	−72.86
	aq, 400	−101.14	
KCN	c	−28.1	
	aq, 400	−25.3	−28.08
KCNO	c	−99.6	
	aq	−94.5	−90.85
KCNS	c	−47.0	
	aq, 400	−41.07	−44.08
K_2CO_3	c	−274.01	
	aq, 400	−280.90	−264.04
$K_2C_2O_4$	c	−319.9	
	aq, 400	−315.5	−293.1
K_2CrO_4	c	−333.4	
	aq, 400	−328.2	−306.3
$K_2Cr_2O_7$	c	−488.5	
	aq, 400	−472.1	−440.9
KF	c	−134.50	
	aq, 180	−138.36	−133.13
$K_3Fe(CN)_6$	c	−48.4	
	aq	−34.5	
$K_4Fe(CN)_6$	c	−131.8	
	aq	−119.9	
KH	c	−10	−5.3
$KHCO_3$	c	−229.8	
	aq, 2000	−224.85	−207.71
KI	c	−78.88	−77.37
	aq, 500	−73.95	−79.76
KIO_3	c	−121.69	−101.87
	aq, 400	−115.18	−99.68
KIO_4	aq	−98.1	
$KMnO_4$	c	−192.9	−169.1
	aq, 400	−182.5	−168.0
K_2MoO_4	aq, 880	−364.2	−342.9
Potassium (*Cont.*)			
KNH_2	c	−28.25	
KNO_2	aq	−86.0	−75.9
KNO_3	c	−118.08	−94.29
	aq, 400	−109.79	−93.68
K_2O	c	−86.2	
$K_2O{\cdot}Al_2O_3{\cdot}SiO_2$	c, leucite	−1379.6	
	gls	−1368.2	
$K_2O{\cdot}Al_2O_3{\cdot}SiO_2$	c, adularia	−1784.5	
	c, microcline	−1784.5	
	gls	−1747	
KOH	c	−102.02	
	aq, 400	−114.96	−105.0
K_3PO_3	aq	−397.5	
K_3PO_4	aq	−478.7	−443.3
KH_2PO_4	c	−362.7	−326.1
K_2PtCl_4	c	−254.7	
	aq	−242.6	−226.5
K_2PtCl_6	c	−299.5	−263.6
	aq, 9400	−286.1	
K_2Se	c	−74.4	
	aq	−83.4	−99.10
K_2SeO_4	aq	−267.1	−240.0
K_2S	c	−121.5	
	aq, 400	−110.75	−111.44
K_2SO_3	c	−267.7	
	aq	−269.7	−251.3
K_2SO_4	c	−342.65	−314.62
	aq, 400	−336.48	−310.96
$K_2SO_4{\cdot}Al_2(SO_4)_3$	c	−1178.38	−1068.48
$K_2SO_4{\cdot}Al_2(SO_4)_3{\cdot}$ $24H_2O$	c	−2895.44	−2455.68
$K_2S_2O_6$	c	−418.62	
Rhenium			
Re	c	0.00	0.00
ReF_6	g	−274	
Rhodium			
Rh	c	0.00	0.00
RhO	c	−21.7	
Rh_2O	c	−22.7	
Rh_2O_3	c	−68.3	
Rubidium			
Rb	c	0.00	0.00
RbBr	c	−95.82	
	g	−45.0	−52.50
	aq, 500	−90.54	−93.38
RbCN	aq	−25.9	
Rb_2CO_3	c	−273.22	
	aq, 220	−282.61	−263.78
RbCl	c	−105.06	−98.48
	g	−53.6	−57.9
	aq, ∞	−101.06	−100.13
RbF	c	−133.23	
	aq, 400	−139.31	−134.5
$RbHCO_3$	c	−230.01	
	aq, 2000	−225.59	−209.07
RbI	c	−81.04	
	g	−31.2	−40.5
	aq, 400	−74.57	−81.13
$RbNH_2$	c	−27.74	
$RbNO_3$	c	−119.22	
	aq, 400	−110.52	−95.05
Rb_2O	c	−82.9	
Rb_2O_2	c	−107	
RbOH	c	−101.3	
	aq, 200	−115.8	−106.39
Ruthenium			
Ru	c	0.00	0.00
RuS_2	c	−46.99	−44.11
Selenium			
Se	c, I, hexagonal	0.00	0.00

TABLE 2-178 Heats and Free Energies of Formation of Inorganic Compounds (*Continued*)

Compound	State†	Heat of formation‡§ ΔH (formation) at 25 °C, kcal/mol	Free energy of formation‖¶ ΔF (formation) at 25 °C, kcal/mol
Selenium (*Cont.*)			
	c, II, red, monoclinic	0.2	
Se_2Cl_2	l	−22.06	−13.73
SeF_6	g	−246	−222
SeO_2	c	−56.33	
Silicon			
Si	c	0.00	0.00
$SiBr_4$	l	−93.0	
SiC	c	−28	−27.4
$SiCl_4$	l	−150.0	−133.9
	g	−142.5	−133.0
SiF_4	g	−370	−360
SiH_4	g	−14.8	−9.4
SiI_4	c	−29.8	
Si_3N_4	c	−179.25	−154.74
SiO_2	c, cristobalite, 1600° form	−202.62	
	c, cristobalite, 1100° form	−202.46	
	c, quartz	−203.35	−190.4
	c, tridymite	−203.23	
Silver			
Ag	c	0.00	0.00
AgBr	c	−23.90	−23.02
Ag_2C_2	c	84.5	
$AgC_2H_3O_2$	c	−95.9	
	aq	−91.7	−70.86
AgCN	c	33.8	38.70
Ag_2CO_3	c	−119.5	−103.0
$Ag_2C_2O_4$	c	−158.7	
AgCl	c	−30.11	−25.98
AgF	c	−48.7	
	aq, 400	−53.1	−47.26
AgI	c	−15.14	−16.17
$AgIO_3$	c	−42.02	−24.08
$AgNO_2$	c	−11.6	3.76
	aq	−2.9	9.99
$AgNO_3$	c	−29.4	−7.66
	aq, 6500	−24.02	−7.81
Ag_2O	c	−6.95	−2.23
Ag_2S	c	−5.5	−7.6
Ag_2SO_4	c	−170.1	−146.8
	aq	−165.8	−139.22
Sodium			
Na	c	0.00	0.00
Na_3AsO_3	aq, 500	−314.61	
Na_3AsO_4	c	−366	
	aq, 500	−381.97	−341.17
NaBr	c	−86.72	
	aq, 400	−86.33	−87.17
NaBrO	aq	−78.9	
$NaBrO_3$	aq, 400	−68.89	−57.59
$NaC_2H_3O_2$	c	−170.45	
	aq, 400	−175.450	−152.31
NaCN	c	−22.47	
	aq, 200	−22.29	−23.24
NaCNO	c	−96.3	
	aq	−91.7	−86.00
NaCNS	c	−39.94	
	aq, 400	−38.23	−39.24
Na_2CO_3	c	−269.46	−249.55
	aq, 1000	−275.13	−251.36
$NaCO_2NH_2$	c	−142.17	
$Na_2C_2O_4$	c	−313.8	
	aq, 600	−309.92	−283.42
NaCl	c	−98.321	−91.894
	aq, 400	−97.324	−93.92
$NaClO_3$	c	−83.59	
	aq, 400	−78.42	−62.84
$NaClO_4$	c	−101.12	
Sodium (*Cont.*)			
	aq, 476	−97.66	−73.29
Na_2CrO_4	c	−319.8	
	aq, 800	−323.0	−296.58
$Na_2Cr_2O_7$	aq, 1200	−465.9	−431.18
NaF	c	−135.94	−129.0
	aq, 400	−135.711	−128.29
NaH	c	−14	−9.30
$NaHCO_3$	c	−226.0	−202.66
	aq	−222.1	−202.87
NaI	c	−69.28	
	aq, ∞	−71.10	−74.92
$NaIO_3$	aq, 400	−112.300	−94.84
Na_2MoO_4	c	−364	
	aq	−358.7	−333.18
$NaNO_2$	c	−86.6	
	aq	−83.1	−71.04
$NaNO_3$	c	−111.71	−87.62
	aq, 400	−106.880	−88.84
Na_2O	c	−99.45	−90.06
Na_2O_2	c	−119.2	−105.0
$Na_2O{\cdot}SiO_2$	c	−383.91	−361.49
$Na_2O{\cdot}Al_2O_3{\cdot}3SiO_2$	c, natrolite	−1180	
$Na_2O{\cdot}Al_2O_3{\cdot}4SiO_2$	c	−1366	
NaOH	c	−101.96	−90.60
	aq, 400	−112.193	−100.18
Na_3PO_3	aq, 1000	−389.1	
Na_3PO_4	c	−457	
	aq, 400	−471.9	−428.74
Na_2PtCl_4	aq	−237.2	−216.78
Na_2PtCl_6	c	−272.1	
	aq	−280.9	
Na_2Se	c	−59.1	
	aq, 440	−78.1	−89.42
Na_2SeO_4	c	−254	
	aq, 800	−261.5	−230.30
Na_2S	c	−89.8	
	aq, 400	−105.17	−101.76
Na_2SO_3	c	−261.2	−240.14
	aq, 800	−264.1	−241.58
Na_2SO_4	c	−330.50	−302.38
	aq, 1100	−330.82	−301.28
$Na_2SO_4{\cdot}10H_2O$	c	−1033.85	−870.52
Na_2WO_4	c	−391	
	aq	−381.5	−345.18
Strontium			
Sr	c	0.00	0.00
$SrBr_2$	c	−171.0	
	aq, 400	−187.24	−182.36
$Sr(C_2H_3O_2)_2$	c	−358.0	
	aq	−364.4	−311.80
$Sr(CN)_2$	aq	−59.5	−54.50
$SrCO_3$	c	−290.9	−271.9
$SrCl_2$	c	−197.84	
	aq, 400	−209.20	−195.86
SrF_2	c	−289.0	
$Sr(HCO_3)_2$	aq	−459.1	−413.76
SrI_2	c	−136.1	
	aq, 400	−156.70	−157.87
Sr_3N_2	c	−91.4	−76.5
$Sr(NO_3)_2$	c	−233.2	
	aq, 400	−228.73	−185.70
SrO	c	−140.8	−133.7
$SrO{\cdot}SiO_2$	gls	−364	
SrO_2	c	−153.3	−139.0
Sr_2O	c	−153.6	
$Sr(OH)_2$	c	−228.7	
	aq, 800	−239.4	−208.27
$Sr_3(PO_4)_2$	c	−980	
	aq	−985	−881.54
SrS	c	−113.1	

TABLE 2-178 Heats and Free Energies of Formation of Inorganic Compounds (*Continued*)

Compound	State†	Heat of formation‡§ ΔH (formation) at 25 °C, kcal/mol	Free energy of formation‖¶ ΔF (formation) at 25 °C, kcal/mol
Strontium (*Cont.*)			
	aq	−120.4	−109.78
$SrSO_4$	c	−345.3	
	aq, 400	−345.0	−309.30
$SrWO_4$	c	−393	
Sulfur			
S	c, rhombic	0.00	0.00
	c, monoclinic	−0.071	0.023
	l, λ	0.257	0.072
	l, λμ equilibrium		0.071
	g	53.25	43.57
S_2	g	31.02	19.36
S_6	g	27.78	13.97
S_8	g	27.090	12.770
S_2Br_2	l	−4	
SCl_4	l	−13.7	
S_2Cl_2	l	−14.2	−5.90
S_2Cl_4	l	−24.1	
SF_6	g	−262	−237
SO	g	19.02	12.75
SO_2	g	−70.94	−71.68
SO_3	g	−94.39	−88.59
	l	−103.03	−88.28
	c, α	−105.09	−88.22
	c, β	−105.92	−88.34
	c, γ	−109.34	−88.98
SO_2Cl_2	g	−82.04	−74.06
	l	−89.80	−75.06
Tantalum			
Ta	c	0.00	0.00
TaN	c	−51.2	−45.11
Ta_2O_5	c	−486.0	−453.7
Tellurium			
Te	c	0.00	0.00
$TeBr_4$	c	−49.3	
$TeCl_4$	c	−77.4	−57.4
TeF_6	g	−315	−292
TeO_2	c	−77.56	−64.66
Thallium			
Tl	c	0.00	0.00
TlBr	c	−41.5	−39.43
	aq	−28.0	−32.34
TlCl	c	−49.37	−44.46
	aq	−38.4	−39.09
$TlCl_3$	c	−82.4	
	aq	−91.0	−44.25
TlF	aq	−77.6	−73.46
TlI	c	−31.1	−31.3
	aq	−12.7	−20.09
$TlNO_3$	c	−58.2	−36.32
	aq	−48.4	−34.01
Tl_2O	c	−43.18	
Tl_2O_3	c	−120	
TlOH	c	−57.44	−45.54
	aq	−53.9	−45.35
Tl_2S	c	−22	
Tl_2SO_4	c	−222.8	−197.79
	aq, 800	−214.1	−191.62
Thorium			
Th	c	0.00	0.00
$ThBr_4$	c	−281.5	
	aq	−352.0	−295.31
ThC_2	c	−45.1	
$ThCl_4$	c	−335	
	aq	−392	−322.32
ThI_4	aq	−292.0	−246.33
Th_3N_4	c	−309.0	−282.3
ThO_2	c	−291.6	−280.1
$Th(OH)_4$	c, "soluble"	−336.1	
$Th(SO_4)_2$	c	−632	
	aq	−668.1	−549.2
Tin			
Sn	c, II, tetragonal	0.00	0.00
	c, III, "gray," cubic	0.6	1.1
$SnBr_2$	c	−61.4	
	aq	−60.0	−55.43
$SnBr_4$	c	−94.8	
	aq	−110.6	−97.66
$SnCl_2$	c	−83.6	
	aq	−81.7	−68.94
$SnCl_4$	l	−127.3	−110.4
	aq	−157.6	−124.67
SnI_2	c	−38.9	
	aq	−33.3	−30.95
SnO	c	−67.7	−60.75
SnO_2	c	−138.1	−123.6
$Sn(OH)_2$	c	−136.2	−115.95
$Sn(OH)_4$	c	−268.9	−226.00
SnS	c	−18.61	
Titanium			
Ti	c	0.00	0.00
TiC	c	−110	−109.2
$TiCl_4$	l	−181.4	−165.5
TiN	c	−80.0	−73.17
TiO_2	c, III, rutil	−225.0	−211.9
	amorphous	−214.1	−201.4
Tungsten			
W	c	0.00	0.00
WO_2	c	−130.5	−118.3
WO_3	c	−195.7	−177.3
WS_2	c	−84	
Uranium			
U	c	0.00	0.00
UC_2	c	−29	
UCl_3	c	−213	
UCl_4	c	−251	
U_3N_4	c	−274	−249.6
UO_2	c	−256.6	−242.2
$UO_2(NO_3)_2 \cdot 6H_2O$	c	−756.8	−617.8
UO_3	c	−291.6	
U_3O_8	c	−845.1	
Vanadium			
V	c	0.00	0.00
VCl_2	c	−147	
VCl_3	l	−187	
VCl_4	l	−165	
VN	c	−41.43	−35.08
V_2O_2	c	−195	
V_2O_3	c	−296	−277
V_2O_4	c	−342	−316
V_2O_5	c	−373	−342
Zinc			
Zn	c	0.00	0.00
ZnSb	c	−3.6	−3.88
$ZnBr_2$	c	−77.0	−72.9
	aq, 400	−93.6	
$Zn(C_2H_3O_2)_2$	c	−259.4	
	aq, 400	−269.4	−214.4
$Zn(CN)_2$	c	17.06	
$ZnCO_3$	c	−192.9	−173.5
$ZnCl_2$	c	−99.9	−88.8
	aq, 400	−115.44	
ZnF_2	aq	−192.9	−166.6
ZnI_2	c	−50.50	−49.93
	aq	−61.6	
$Zn(NO_3)_2$	aq, 400	−134.9	−87.7
ZnO	c, hexagonal	−83.36	−76.19
$ZnO \cdot SiO_2$	c	−282.6	
$Zn(OH)_2$	c, rhombic	−153.66	
ZnS	c, wurtzite	−45.3	−44.2
$ZnSO_4$	c	−233.4	
	aq, 400	−252.12	−211.28

TABLE 2-178 Heats and Free Energies of Formation of Inorganic Compounds (*Concluded*)

Compound	State†	Heat of formation‡§ ΔH (formation) at 25 °C, kcal/mol	Free energy of formation‖¶ ΔF (formation) at 25 °C, kcal/mol	Compound	State†	Heat of formation‡§ ΔH (formation) at 25 °C, kcal/mol	Free energy of formation‖¶ ΔF (formation) at 25 °C, kcal/mol
Zirconium				Zirconium (*Cont.*)			
Zr	c	0.00	0.00	ZrO_2	c, monoclinic	–258.5	–244.6
ZrC	c	–29.8	–34.6	$Zr(OH)_4$	c	–411.0	
$ZrCl_4$	c	–268.9		$ZrO(OH)_2$	c	–337	–307.6
ZrN	c	–82.5	–75.9				

† The physical state is indicated as follows: *c,* crystal (solid); *l,* liquid; *g,* gas; *gls,* glass or solid supercooled liquid; *aq,* in aqueous solution. A number following the symbol *aq* applies only to the values of the heats of formation (not to those of free energies of formation); and indicates the number of moles of water per mole of solute; when no number is given, the solution is understood to be dilute. For the free energy of formation of a substance in aqueous solution, the concentration is always that of the hypothetical solution of unit molality.

‡ The increment in heat content, ΔH, is the reaction of forming the given substance from its elements in their standard states. When ΔH is negative, heat is evolved in the process, and, when positive, heat is absorbed.

§ The heat of solution in water of a given solid, liquid, or gaseous compound is given by the difference in the value for the heat of formation of the given compound in the solid, liquid, or gaseous state and its heat of formation in aqueous solution. The following two examples serve as an illustration of the procedure: (1) For NaCl(*c*) and NaCl(*aq,* $400H_2O$), the values of ΔH(formation) are, respectively, –98.321 and –97.324 kcal/mol. Subtraction of the first value from the second gives $\Delta H = 0.998$ kcal/mol for the reaction of dissolving crystalline sodium chloride in 400 mol of water. When this process occurs at a constant pressure of 1 atm, 0.998 kg-cal of energy are absorbed. (2) For HCl(*g*) and HCl(*aq,* $400H_2O$), the values for ΔH(formation) are, respectively, –22.06 and –39.85 kcal/mol. Subtraction of the first from the second gives $\Delta H = -17.79$ kcal/mol for the reaction of dissolving gaseous hydrogen chloride in 400 mol of water. At a constant pressure of 1 atm, 17.79 kcal of energy are evolved in this process.

‖ The increment in the free energy, ΔF, is the reaction of forming the given substance in its standard state from its elements in their standard states. The standard states are: for a gas, fugacity (approximately equal to the pressure) of 1 atm; for a pure liquid or solid, the substance at a pressure of 1 atm; for a substance in aqueous solution, the hypothetical solution of unit molality, which has all the properties of the infinitely dilute solution except the property of concentration.

¶ The free energy of solution of a given substance from its normal standard state as a solid, liquid, or gas to the hypothetical one molal state in aqueous solution may be calculated in a manner similar to that described in footnote § for calculating the heat of solution.

TABLE 2-179 Enthalpies and Gibbs Energies of Formation, Entropies, and Net Enthalpies of Combustion of Inorganic and Organic Compounds at 298.15 K

Cmpd. no.	Name	Formula	CAS no.	Mol. wt.	Ideal gas enthalpy of formation, J/kmol × 1E-07	Ideal gas Gibbs energy of formation, J/kmol × 1E-07	Ideal gas entropy, J/(kmol·K) × 1E-05	Standard net enthalpy of combustion, J/kmol × 1E-09
1	Acetaldehyde	C_2H_4O	75-07-0	44.053	–16.64	–13.33	2.642	–1.1045
2	Acetamide	C_2H_5NO	60-35-5	59.067	–23.83	–15.96	2.722	–1.0741
3	Acetic acid	$C_2H_4O_2$	64-19-7	60.052	–46.11	–40.3	2.825	–0.7866
4	Acetic anhydride	$C_4H_6O_3$	108-24-7	102.089	–57.25	–47.34	3.899	–1.675
5	Acetone	C_3H_6O	67-64-1	58.079	–21.57	–15.13	2.954	–1.659
6	Acetonitrile	C_2H_3N	75-05-8	41.052	7.404	9.1868	2.4329	–1.19043
7	Acetylene	C_2H_2	74-86-2	26.037	22.82	21.068	2.0081	–1.257
8	Acrolein	C_3H_4O	107-02-8	56.063	–8.18	–5.68	2.97	–1.5468
9	Acrylic acid	$C_3H_4O_2$	79-10-7	72.063	–35.591	–30.6	3.15	–1.32717
10	Acrylonitrile	C_3H_3N	107-13-1	53.063	18.37	19.37	2.753	–1.69
11	Air	Mixture	132259-10-0	28.960	0	0	1.99	0
12	Ammonia	H_3N	7664-41-7	17.031	–4.5898	–1.64	1.9266	–0.31683
13	Anisole	C_7H_8O	100-66-3	108.138	–6.79	2.27	3.61	–3.6072
14	Argon	Ar	7440-37-1	39.948	0	0	1.54737	0
15	Benzamide	C_7H_7NO	55-21-0	121.137	–10.09	–0.211	3.641	–3.39877
16	Benzene	C_6H_6	71-43-2	78.112	8.288	12.96	2.693	–3.136
17	Benzenethiol	C_6H_6S	108-98-5	110.177	11.15	14.76	3.369	–3.4474
18	Benzoic acid	$C_7H_6O_2$	65-85-0	122.121	–29.41	–21.42	3.69	–3.0951
19	Benzonitrile	C_7H_5N	100-47-0	103.121	21.57	25.78	3.21	–3.5238
20	Benzophenone	$C_{13}H_{10}O$	119-61-9	182.218	5.68	17.3	4.4	–6.2876
21	Benzyl alcohol	C_7H_8O	100-51-6	108.138	–9.025	–0.254	3.713	–3.56
22	Benzyl ethyl ether	$C_9H_{12}O$	539-30-0	136.191	–11.5	3.37	4.39	–4.83
23	Benzyl mercaptan	C_7H_8S	100-53-8	124.203	9.33	16.3	3.607	–4.06
24	Biphenyl	$C_{12}H_{10}$	92-52-4	154.208	17.849	27.63	3.9367	–6.248
25	Bromine	Br_2	7726-95-6	159.808	3.091	0.314	2.4535	
26	Bromobenzene	C_6H_5Br	108-86-1	157.008	10.5018	13.8532	3.24386	–3.01917
27	Bromoethane	C_2H_5Br	74-96-4	108.965	–6.36	–2.582	2.873	–1.285
28	Bromomethane	CH_3Br	74-83-9	94.939	–3.77	–2.819	2.458	–0.70542
29	1,2-Butadiene	C_4H_6	590-19-2	54.090	16.23	19.86	2.93	–2.4617
30	1,3-Butadiene	C_4H_6	106-99-0	54.090	10.924	14.972	2.7889	–2.409
31	Butane	C_4H_{10}	106-97-8	58.122	–12.579	–1.67	3.0991	–2.65732
32	1,2-Butanediol	$C_4H_{10}O_2$	584-03-2	90.121	–44.58	–30.44	4.065	–2.2678
33	1,3-Butanediol	$C_4H_{10}O_2$	107-88-0	90.121	–43.32	–29.18	4.065	–2.2824
34	1-Butanol	$C_4H_{10}O$	71-36-3	74.122	–27.51	–15.07	3.618	–2.454
35	2-Butanol	$C_4H_{10}O$	78-92-2	74.122	–29.29	–16.7	3.566	–2.446
36	1-Butene	C_4H_8	106-98-9	56.106	–0.05	7.041	3.074	–2.5408
37	*cis*-2-Butene	C_4H_8	590-18-1	56.106	–0.74	6.536	3.012	–2.5339
38	*trans*-2-Butene	C_4H_8	624-64-6	56.106	–1.1	6.32	2.965	–2.53
39	Butyl acetate	$C_6H_{12}O_2$	123-86-4	116.158	–48.56	–31.26	4.425	–3.28
40	Butylbenzene	$C_{10}H_{14}$	104-51-8	134.218	–1.314	14.54	4.3949	–5.5644
41	Butyl mercaptan	$C_4H_{10}S$	109-79-5	90.187	–8.78	1.139	3.752	–2.9554
42	*sec*-Butyl mercaptan	$C_4H_{10}S$	513-53-1	90.187	–9.66	0.512	3.667	–2.949
43	1-Butyne	C_4H_6	107-00-6	54.090	16.52	20.225	2.9039	–2.4647
44	Butyraldehyde	C_4H_8O	123-72-8	72.106	–20.7	–11.63	3.4365	–2.3035
45	Butyric acid	$C_4H_8O_2$	107-92-6	88.105	–47.58	–36	3.601	–2.008
46	Butyronitrile	C_4H_7N	109-74-0	69.105	3.40578	10.8658	3.25432	–2.4148
47	Carbon dioxide	CO_2	124-38-9	44.010	–39.351	–39.437	2.13677	
48	Carbon disulfide	CS_2	75-15-0	76.141	11.69	6.68	2.379	–1.0769
49	Carbon monoxide	CO	630-08-0	28.010	–11.053	–13.715	1.97556	–0.283
50	Carbon tetrachloride	CCl_4	56-23-5	153.823	–9.581	–5.354	3.0991	–0.2653
51	Carbon tetrafluoride	CF_4	75-73-0	88.004	–92.21	–87.76	2.62	0.5286
52	Chlorine	Cl_2	7782-50-5	70.906	0	0	2.22972	
53	Chlorobenzene	C_6H_5Cl	108-90-7	112.557	5.109	9.829	3.1403	–2.976
54	Chloroethane	C_2H_5Cl	75-00-3	64.514	–11.226	–6.0499	2.7578	–1.2849
55	Chloroform	$CHCl_3$	67-66-3	119.378	–10.29	–7.01	2.956	–0.38
56	Chloromethane	CH_3Cl	74-87-3	50.488	–8.196	–5.844	2.3418	–0.67538
57	1-Chloropropane	C_3H_7Cl	540-54-5	78.541	–13.318	–5.261	3.1547	–1.867
58	2-Chloropropane	C_3H_7Cl	75-29-6	78.541	–14.477	–6.136	3.0594	–1.863

TABLE 2-179 Enthalpies and Gibbs Energies of Formation, Entropies, and Net Enthalpies of Combustion of Inorganic and Organic Compounds at 298.15 K (*Continued*)

Cmpd. no.	Name	Formula	CAS no.	Mol. wt.	Ideal gas enthalpy of formation, J/kmol × 1E-07	Ideal gas Gibbs energy of formation, J/kmol × 1E-07	Ideal gas entropy, J/(kmol·K) × 1E-05	Standard net enthalpy of combustion, J/kmol × 1E-09
59	*m*-Cresol	C_7H_8O	108-39-4	108.138	–13.23	–4.019	3.5604	–3.52783
60	*o*-Cresol	C_7H_8O	95-48-7	108.138	–12.857	–3.543	3.5259	–3.528
61	*p*-Cresol	C_7H_8O	106-44-5	108.138	–12.535	–3.166	3.5075	–3.52256
62	Cumene	C_9H_{12}	98-82-8	120.192	0.4	13.79	3.86	–4.951
63	Cyanogen	C_2N_2	460-19-5	52.035	30.9072	29.7598	2.41463	–1.0961
64	Cyclobutane	C_4H_8	287-23-0	56.106	2.85	11.22	2.64396	–2.5678
65	Cyclohexane	C_6H_{12}	110-82-7	84.159	–12.33	3.191	2.97276	–3.656
66	Cyclohexanol	$C_6H_{12}O$	108-93-0	100.159	–28.62	–10.95	3.277	–3.4639
67	Cyclohexanone	$C_6H_{10}O$	108-94-1	98.143	–22.61	–9.028	3.3426	–3.299
68	Cyclohexene	C_6H_{10}	110-83-8	82.144	–0.46	10.77	3.10518	–3.532
69	Cyclopentane	C_5H_{10}	287-92-3	70.133	–7.703	3.885	2.929	–3.0709
70	Cyclopentene	C_5H_8	142-29-0	68.117	3.23	11.05	2.91267	–2.9393
71	Cyclopropane	C_3H_6	75-19-4	42.080	5.33	10.44	2.37378	–1.9593
72	Cyclohexyl mercaptan	$C_6H_{12}S$	1569-69-3	116.224	–9.602	4.886	3.646	–3.968
73	Decanal	$C_{10}H_{20}O$	112-31-2	156.265	–33.17	–6.739	5.7912	–5.959
74	Decane	$C_{10}H_{22}$	124-18-5	142.282	–24.946	3.318	5.457	–6.29422
75	Decanoic acid	$C_{10}H_{20}O_2$	334-48-5	172.265	–59.43	–30.5	5.99	–5.72
76	1-Decanol	$C_{10}H_{22}O$	112-30-1	158.281	–39.85	–10.02	5.971	–6.116
77	1-Decene	$C_{10}H_{20}$	872-05-9	140.266	–12.21	12.27	5.433	–6.1809
78	Decyl mercaptan	$C_{10}H_{22}S$	143-10-2	174.347	–21.09	6.165	6.116	–6.6161
79	1-Decyne	$C_{10}H_{18}$	764-93-2	138.250	4.1	25.16	5.263	–6.1037
80	Deuterium	D_2	7782-39-0	4.032	0	0	1.4486	–0.24625
81	1,1-Dibromoethane	$C_2H_4Br_2$	557-91-5	187.861	–4.08	–1.181	3.276	–1.16
82	1,2-Dibromoethane	$C_2H_4Br_2$	106-93-4	187.861	–3.89	–1.054	3.297	–1.1769
83	Dibromomethane	CH_2Br_2	74-95-3	173.835			2.92964	
84	Dibutyl ether	$C_8H_{18}O$	142-96-1	130.228	–33.34	–8.827	5.014	–4.94691
85	*m*-Dichlorobenzene	$C_6H_4Cl_2$	541-73-1	147.002	2.57	7.79	3.4353	–2.825
86	*o*-Dichlorobenzene	$C_6H_4Cl_2$	95-50-1	147.002	3.02	8.29	3.4185	–2.826
87	*p*-Dichlorobenzene	$C_6H_4Cl_2$	106-46-7	147.002	2.25	7.67	3.3674	–2.802
88	1,1-Dichloroethane	$C_2H_4Cl_2$	75-34-3	98.959	–12.941	–7.259	3.0501	–1.1104
89	1,2-Dichloroethane	$C_2H_4Cl_2$	107-06-2	98.959	–12.979	–7.3945	3.0828	–1.105
90	Dichloromethane	CH_2Cl_2	75-09-2	84.933	–9.552	–6.896	2.7018	–0.51388
91	1,1-Dichloropropane	$C_3H_6Cl_2$	78-99-9	112.986	–15.08	–6.52	3.448	–1.72
92	1,2-Dichloropropane	$C_3H_6Cl_2$	78-87-5	112.986	–16.28	–8.018	3.548	–1.707
93	Diethanol amine	$C_4H_{11}NO_2$	111-42-2	105.136	–40.847	–22.574	4.29	–2.4105
94	Diethyl amine	$C_4H_{11}N$	109-89-7	73.137	–7.142	7.308	3.522	–2.8003
95	Diethyl ether	$C_4H_{10}O$	60-29-7	74.122	–25.21	–12.21	3.423	–2.5035
96	Diethyl sulfide	$C_4H_{10}S$	352-93-2	90.187	–8.356	1.774	3.681	–2.9607
97	1,1-Difluoroethane	$C_2H_4F_2$	75-37-6	66.050	–49.7	–43.9485	2.824	–0.773662
98	1,2-Difluoroethane	$C_2H_4F_2$	624-72-6	66.050	–44.77	–39.19	2.88194	–0.823
99	Difluoromethane	CH_2F_2	75-10-5	52.023	–45.23	–42.4747	2.4658	–0.183031
100	Di-isopropyl amine	$C_6H_{15}N$	108-18-9	101.190	–14.38	6.42	4.12	–3.99
101	Di-isopropyl ether	$C_6H_{14}O$	108-20-3	102.175	–31.92	–12.48	3.989	–3.70261
102	Di-isopropyl ketone	$C_7H_{14}O$	565-80-0	114.185	–31.14	–12.37	4.27	–4.095
103	1,1-Dimethoxyethane	$C_4H_{10}O_2$	534-15-6	90.121	–38.97	–23.8	3.726	–2.394
104	1,2-Dimethoxypropane	$C_5H_{12}O_2$	7778-85-0	104.148	–38.42	–20.11	4.038	–2.996
105	Dimethyl acetylene	C_4H_6	503-17-3	54.090	14.57	18.49	2.833	–2.4189
106	Dimethyl amine	C_2H_7N	124-40-3	45.084	–1.845	6.839	2.7296	–1.6146
107	2,3-Dimethylbutane	C_6H_{14}	79-29-8	86.175	–17.68	–0.3125	3.6592	–3.84761
108	1,1-Dimethylcyclohexane	C_8H_{16}	590-66-9	112.213	–18.1	3.52293	3.65012	–4.8639
109	*cis*-1,2-Dimethylcyclohexane	C_8H_{16}	2207-01-4	112.213	–17.2172	4.12124	3.7451	–4.87084
110	*trans*-1,2-Dimethylcyclohexane	C_8H_{16}	6876-23-9	112.213	–17.9996	3.44761	3.70912	–4.86436
111	Dimethyl disulfide	$C_2H_6S_2$	624-92-0	94.199	–2.42	1.516	3.35291	–2.0441
112	Dimethyl ether	C_2H_6O	115-10-6	46.068	–18.41	–11.28	2.667	–1.3284
113	*N*,*N*-Dimethyl formamide	C_3H_7NO	68-12-2	73.094	–19.17	–8.84	3.26	–1.78871
114	2,3-Dimethylpentane	C7H16	565-59-3	100.202	–19.41	0.5717	4.1455	–4.46075
115	Dimethyl phthalate	$C_{10}H_{10}O_4$	131-11-3	194.184	–60.5	–46.7749	6.6	–4.4662
116	Dimethylsilane	C_2H_8Si	1111-74-6	60.170	–9.47	–1.925	2.9953	–2.569

117	Dimethyl sulfide	C_2H_6S	75-18-3	62.134	–3.724	0.7302	2.8585	–1.7443
118	Dimethyl sulfoxide	C_2H_6OS	67-68-5	78.133	–15.046	–8.1441	3.0627	–1.6054
119	Dimethyl terephthalate	$C_{10}H_{10}O_4$	120-61-6	194.184	–64.4	–47.4	5.5	–4.4115
120	1,4-Dioxane	$C_4H_8O_2$	123-91-1	88.105	–31.58	–18.16	3.0012	–2.1863
121	Diphenyl ether	$C_{12}H_{10}O$	101-84-8	170.207	5.2	17.5	4.13	–5.8939
122	Dipropyl amine	$C_6H_{15}N$	142-84-7	101.190	–11.6	8.68	4.29	–4.0189
123	Dodecane	$C_{12}H_{26}$	112-40-3	170.335	–29.072	4.981	6.2415	–7.51368
124	Eicosane	$C_{20}H_{42}$	112-95-8	282.547	–45.646	11.57	9.3787	–12.3908
125	Ethane	C_2H_6	74-84-0	30.069	–8.382	–3.192	2.2912	–1.42864
126	Ethanol	C_2H_6O	64-17-5	46.068	–23.495	–16.785	2.8064	–1.235
127	Ethyl acetate	$C_4H_8O_2$	141-78-6	88.105	–44.45	–32.8	3.597	–2.061
128	Ethyl amine	C_2H_7N	75-04-7	45.084	–4.715	3.616	2.848	–1.5874
129	Ethylbenzene	C_8H_{10}	100-41-4	106.165	2.992	13.073	3.6063	–4.3448
130	Ethyl benzoate	$C_9H_{10}O_2$	93-89-0	150.175	–32.6	–19.05	4.55	–4.41
131	2-Ethyl butanoic acid	$C_6H_{12}O_2$	88-09-5	116.158	–53.78	–35.9	4.23	–3.21203
132	Ethyl butyrate	$C_6H_{12}O_2$	105-54-4	116.158	–48.55	–31.22	4.417	–3.284
133	Ethylcyclohexane	C_8H_{16}	1678-91-7	112.213	–17.15	3.955	3.826	–4.87051
134	Ethylcyclopentane	C_7H_{14}	1640-89-7	98.186	–12.69	4.48	3.783	–4.2839
135	Ethylene	C_2H_4	74-85-1	28.053	5.251	6.844	2.192	–1.323
136	Ethylenediamine	$C_2H_8N_2$	107-15-3	60.098	–1.73	10.3	3.21833	–1.691
137	Ethylene glycol	$C_2H_6O_2$	107-21-1	62.068	–39.22	–30.18	3.04891	–1.0527
138	Ethyleneimine	C_2H_5N	151-56-4	43.068	12.3428	17.7987	2.5062	–1.481
139	Ethylene oxide	C_2H_4O	75-21-8	44.053	–5.263	–1.323	2.4299	–1.218
140	Ethyl formate	$C_3H_6O_2$	109-94-4	74.079	–38.83	–30.31	3.282	–1.50696
141	2-Ethyl hexanoic acid	$C_8H_{16}O_2$	149-57-5	144.211	–55.95	–32.5	5.1	–4.448
142	Ethylhexyl ether	$C_8H_{18}O$	5756-43-4	130.228	–33.37	–9.042	5.076	–4.943
143	Ethylisopropyl ether	$C_5H_{12}O$	625-54-7	88.148	–28.58	–12.64	3.8	–3.103
144	Ethylisopropyl ketone	$C_6H_{12}O$	565-69-5	100.159	–28.61	–13.3	4.069	–3.4863
145	Ethyl mercaptan	C_2H_6S	75-08-1	62.134	–4.63	–0.4814	2.961	–1.7366
146	Ethyl propionate	$C_5H_{10}O_2$	105-37-3	102.132	–46.36	–31.93	4.025	–2.674
147	Ethylpropyl ether	$C_5H_{12}O$	628-32-0	88.148	–27.22	–11.52	3.881	–3.12
148	Ethyltrichlorosilane	$C_2H_5Cl_3Si$	115-21-9	163.506	–59.54	–51.01	4.07	–1.671
149	Fluorine	F_2	7782-41-4	37.997	0	0	2.02682	
150	Fluorobenzene	C_6H_5F	462-06-6	96.102	–11.6566	–6.9036	3.02629	–2.81451
151	Fluoroethane	C_2H_5F	353-36-6	48.060	–26.44	–21.23	2.644	–1.127
152	Fluoromethane	CH_3F	593-53-3	34.033	–23.43	–21.04	2.22734	–0.5219
153	Formaldehyde	CH_2O	50-00-0	30.026	–10.86	–10.26	2.1866	–0.5268
154	Formamide	CH_3NO	75-12-7	45.041	–19.22	–14.71	2.4857	–0.5021
155	Formic acid	CH_2O_2	64-18-6	46.026	–40.55	–37.78	2.487	–0.2115
156	Furan	C_4H_4O	110-00-9	68.074	–3.48	0.08225	2.6714	–1.9959
157	Helium-4	He	7440-59-7	4.003	0	0	1.26044	0
158	Heptadecane	$C_{17}H_{36}$	629-78-7	240.468	–39.445	9.083	8.2023	–10.5618
159	Heptanal	$C_7H_{14}O$	111-71-7	114.185	–26.94	–9.191	4.6138	–4.136
160	Heptane	C_7H_{16}	142-82-5	100.202	–18.765	0.8165	4.2798	–4.46473
161	Heptanoic acid	$C_7H_{14}O_2$	111-14-8	130.185	–53.62	–33.4	4.8	–3.839
162	1-Heptanol	$C_7H_{16}O$	111-70-6	116.201	–33.68	–12.55	4.795	–4.285
163	2-Heptanol	$C_7H_{16}O$	543-49-7	116.201	–35.54	–14.25	4.74	–4.282
164	3-Heptanone	$C_7H_{14}O$	106-35-4	114.185	–30.1	–12.25	4.58	–4.098
165	2-Heptanone	$C_7H_{14}O$	110-43-0	114.185	–30.0453	–11.96	4.486	–4.09952
166	1-Heptene	C_7H_{14}	592-76-7	98.186	–6.289	9.482	4.252	–4.3499
167	Heptyl mercaptan	$C_7H_{16}S$	1639-09-4	132.267	–14.95	3.622	4.939	–4.7865
168	1-Heptyne	C_7H_{12}	628-71-7	96.170	10.3	22.7	4.085	–4.2717
169	Hexadecane	$C_{16}H_{34}$	544-76-3	226.441	–37.417	8.216	7.8102	–9.95145
170	Hexanal	$C_6H_{12}O$	66-25-1	100.159	–24.86	–10.005	4.2214	–3.52
171	Hexane	C_6H_{14}	110-54-3	86.175	–16.694	–0.006634	3.8874	–3.8551
172	Hexanoic acid	$C_6H_{12}O_2$	142-62-1	116.158	–51.19	–33.8	4.41	–3.23
173	1-Hexanol	$C_6H_{14}O$	111-27-3	102.175	–31.62	–13.39	4.402	–3.675
174	2-Hexanol	$C_6H_{14}O$	626-93-7	102.175	–33.46	–15.06	4.349	–3.67
175	2-Hexanone	$C_6H_{12}O$	591-78-6	100.159	–27.9826	–13.0081	4.17856	–3.49
176	3-Hexanone	$C_6H_{12}O$	589-38-8	100.159	–27.76	–12.6	4.092	–3.492
177	1-Hexene	C_6H_{12}	592-41-6	84.159	–4.167	8.7	3.863	–3.7397
178	3-Hexyne	C_6H_{10}	928-49-4	82.144	10.6	19.9	3.76	–3.64
179	Hexyl mercaptan	$C_6H_{14}S$	111-31-9	118.240	–12.92	2.759	4.546	–4.1762

TABLE 2-179 Enthalpies and Gibbs Energies of Formation, Entropies, and Net Enthalpies of Combustion of Inorganic and Organic Compounds at 298.15 K (*Continued*)

Cmpd. no.	Name	Formula	CAS no.	Mol. wt.	Ideal gas enthalpy of formation, J/kmol × 1E-07	Ideal gas Gibbs energy of formation, J/kmol × 1E-07	Ideal gas entropy, J/(kmol·K) × 1E-05	Standard net enthalpy of combustion, J/kmol × 1E-09
180	1-Hexyne	C_6H_{10}	693-02-7	82.144	12.37	21.85	3.694	–3.661
181	2-Hexyne	C_6H_{10}	764-35-2	82.144	10.5	19.9	3.72	–3.64
182	Hydrazine	H_4N_2	302-01-2	32.045	9.5353	15.917	2.3861	–0.5342
183	Hydrogen	H_2	1333-74-0	2.016	0	0	1.30571	–0.24182
184	Hydrogen bromide	HBr	10035-10-6	80.912	–3.629	–5.334	1.98591	–0.06904
185	Hydrogen chloride	HCl	7647-01-0	36.461	–9.231	–9.53	1.86786	–0.0286
186	Hydrogen cyanide	CHN	74-90-8	27.025	13.5143	12.4725	2.01719	–0.62329
187	Hydrogen fluoride	HF	7664-39-3	20.006	–27.33	–27.54	1.7367	0.1524
188	Hydrogen sulfide	H_2S	7783-06-4	34.081	–2.063	–3.344	2.056	–0.518
189	Isobutyric acid	$C_4H_8O_2$	79-31-2	88.105	–48.41	–36.21	3.412	–2.0004
190	Isopropyl amine	C_3H_9N	75-31-0	59.110	–8.38	3.192	3.124	–2.1566
191	Malonic acid	$C_3H_4O_4$	141-82-2	104.061	–76.68	–67	3.7	–0.7732
192	Methacrylic acid	$C_4H_6O_2$	79-41-4	86.089	–36.8	–28.8	3.5	–1.93
193	Methane	CH_4	74-82-8	16.042	–7.452	–5.049	1.8627	–0.80262
194	Methanol	CH_4O	67-56-1	32.042	–20.094	–16.232	2.3988	–0.6382
195	*N*-Methyl acetamide	C_3H_7NO	79-16-3	73.094	–24	–13.5	3.2	–1.71
196	Methyl acetate	$C_3H_6O_2$	79-20-9	74.079	–41.19	–32.42	3.198	–1.461
197	Methyl acetylene	C_3H_4	74-99-7	40.064	18.49	19.384	2.4836	–1.8487
198	Methyl acrylate	$C_4H_6O_2$	96-33-3	86.089	–33.3	–25.7	3.66	–1.9303
199	Methyl amine	CH_5N	74-89-5	31.057	–2.297	3.207	2.433	–0.97508
200	Methyl benzoate	$C_8H_8O_2$	93-58-3	136.148	–28.79	–18.1	4.14	–3.772
201	3-Methyl-1,2-butadiene	C_5H_8	598-25-4	68.117	12.908	19.75	3.2151	–3.032
202	2-Methylbutane	C_5H_{12}	78-78-4	72.149	–15.37	–1.405	3.4374	–3.23954
203	2-Methylbutanoic acid	$C_5H_{10}O_2$	116-53-0	102.132	–49.8	–34.99	3.9	–2.622
204	3-Methyl-1-butanol	$C_5H_{12}O$	123-51-3	88.148	–30.3	–14.1	3.869	–3.062
205	2-Methyl-1-butene	C_5H_{10}	563-46-2	70.133	–3.53	6.668	3.395	–3.1159
206	2-Methyl-2-butene	C_5H_{10}	513-35-9	70.133	–4.18	6.045	3.386	–3.1088
207	2-Methyl -1-butene-3-yne	C_5H_6	78-80-8	66.101	26	30.25	2.78	–2.93
208	Methylbutyl ether	$C_5H_{12}O$	628-28-4	88.148	–25.81	–10.17	3.901	–3.12818
209	Methylbutyl sulfide	$C_5H_{12}S$	628-29-5	104.214	–10.2	2.691	4.118	–3.5723
210	3-Methyl-1-butyne	C_5H_8	598-23-2	68.117	13.8	20.72	3.189	–3.046
211	Methyl butyrate	$C_5H_{10}O_2$	623-42-7	102.132	–45.07	–30.53	3.988	–2.686
212	Methylchlorosilane	CH_5ClSi	993-00-0	80.589	–21.5	–16.61	2.98277	–1.693
213	Methylcyclohexane	C_7H_{14}	108-87-2	98.186	–15.48	2.733	3.433	–4.25714
214	1-Methylcyclohexanol	$C_7H_{14}O$	590-67-0	114.185	–33.2	–12.9	3.75	–4.058
215	cis-2-Methylcyclohexanol	$C_7H_{14}O$	7443-70-1	114.185	–32.7	–12.68	3.853	–4.0574
216	trans-2-Methylcyclohexanol	$C_7H_{14}O$	7443-52-9	114.185	–35.26	–15.24	3.853	–4.0318
217	Methylcyclopentane	C_6H_{12}	96-37-7	84.159	–10.62	3.63	3.399	–3.6741
218	1-Methylcyclopentene	C_6H_{10}	693-89-0	82.144	–0.38	10.38	3.264	–3.534
219	3-Methylcyclopentene	C_6H_{10}	1120-62-3	82.144	0.74	11.38	3.305	–3.5464
220	Methyldichlorosilane	CH_4Cl_2Si	75-54-7	115.034	–40.2	–34.83	3.287	–1.357
221	Methylethyl ether	C_3H_8O	540-67-0	60.095	–21.64	–11.71	3.0881	–1.9314
222	Methylethyl ketone	C_4H_8O	78-93-3	72.106	–23.9	–14.7	3.394	–2.268
223	Methylethyl sulfide	C_3H_8S	624-89-5	76.161	–5.96	1.147	3.332	–2.354
224	Methyl formate	$C_2H_4O_2$	107-31-3	60.052	–35.24	–29.5	2.852	–0.8924
225	Methylisobutyl ether	$C_5H_{12}O$	625-44-5	88.148	–26.6	–10.7	3.81	–3.122
226	Methylisobutyl ketone	$C_6H_{12}O$	108-10-1	100.159	–28.64	–13.51	4.129	–3.4762
227	Methyl Isocyanate	C_2H_3NO	624-83-9	57.051	–6.24	0.0244	1.955	–1.06
228	Methylisopropyl ether	$C_4H_{10}O$	598-53-8	74.122	–25.2	–12.18	3.416	–2.5311
229	Methylisopropyl ketone	$C_5H_{10}O$	563-80-4	86.132	–26.26	–13.93	3.699	–2.877
230	Methylisopropyl sulfide	$C_4H_{10}S$	1551-21-9	90.187	–8.96	1.4509	3.59	–2.957
231	Methyl mercaptan	CH_4S	74-93-1	48.107	–2.29	–0.98	2.55	–1.1517
232	Methyl methacrylate	$C_5H_8O_2$	80-62-6	100.116	–36	–25.4	4.01	–2.54
233	2-Methyloctanoic acid	$C_9H_{18}O_2$	3004-93-1	158.238	–57.95	–31.8	5.533	–5.056
234	2-Methylpentane	C_6H_{14}	107-83-5	86.175	–17.455	–0.5338	3.8089	–3.84915
235	Methyl pentyl ether	$C_6H_{14}O$	628-80-8	102.175	–27.8	–9.35	4.32	–3.739
236	2-Methylpropane	C_4H_{10}	75-28-5	58.122	–13.499	–2.144	2.955	–2.64895
237	2-Methyl-2-propanol	$C_4H_{10}O$	75-65-0	74.122	–31.24	–17.76	3.263	–2.4239

238	2-Methyl propene	C_4H_8	115-11-7	56.106	–1.71	5.808	2.9309	–2.5242
239	Methyl propionate	$C_4H_8O_2$	554-12-1	88.105	–42.75	–31.1	3.596	–2.078
240	Methylpropyl ether	$C_4H_{10}O$	557-17-5	74.122	–23.82	–11.1	3.52	–2.51739
241	Methylpropyl sulfide	$C_4H_{10}S$	3877-15-4	90.187	–8.23	1.793	3.717	–2.962
242	Methylsilane	CH_6Si	992-94-9	46.144	–2.91	1.853	2.565	–1.999
243	alpha-Methyl styrene	C_9H_{10}	98-83-9	118.176	11.83	21.73	3.725	–4.8214
244	Methyl *tert*-butyl ether	$C_5H_{12}O$	1634-04-4	88.148	–28.32	–11.7	3.578	–3.105
245	Methyl vinyl ether	C_3H_6O	107-25-5	58.079	–10.8	–4.73	3.08	–1.77431
246	Naphthalene	$C_{10}H_8$	91-20-3	128.171	15.058	22.408	3.3315	–4.9809
247	Neon	Ne	7440-01-9	20.180	0	0	1.46219	0
248	Nitroethane	$C_2H_5NO_2$	79-24-3	75.067	–10.21	–0.6125	3.168	–1.25
249	Nitrogen	N_2	7727-37-9	28.013	0	0	1.915	
250	Nitrogen trifluoride	F_3N	7783-54-2	71.002	–13.2089	–9.06	2.6062	
251	Nitromethane	CH_3NO_2	75-52-5	61.040	–7.47	–0.6934	2.751	–0.6432
252	Nitrous oxide	N_2O	10024-97-2	44.013	8.205	10.416	2.1985	–0.0820482
253	Nitric oxide	NO	10102-43-9	30.006	9.025	8.657	2.106	–0.0902489
254	Nonadecane	$C_{19}H_{40}$	629-92-5	268.521	–43.579	10.74	8.9866	–11.7812
255	Nonanal	$C_9H_{18}O$	124-19-6	142.239	–31.09	–7.553	5.3988	–5.35
256	Nonane	C_9H_20	111-84-2	128.255	–22.874	2.498	5.064	–5.68455
257	Nonanoic acid	$C_9H_{18}O_2$	112-05-0	158.238	–57.73	–31.7	5.59	–5.061
258	1-Nonanol	$C_9H_{20}O$	143-08-8	144.255	–37.79	–10.86	5.579	–5.506
259	2-Nonanol	$C_9H_{20}O$	628-99-9	144.255	–39.71	–12.61	5.523	–5.506
260	1-Nonene	C_9H_{18}	124-11-8	126.239	–10.35	11.23	5.041	–5.5716
261	Nonyl mercaptan	$C_9H_{20}S$	1455-21-6	160.320	–19.08	5.28	5.724	–6.006
262	1-Nonyne	C_9H_{16}	3452-09-3	124.223	6.17	24.34	4.8699	–5.493
263	Octadecane	$C_{18}H_{38}$	593-45-3	254.494	–41.512	9.91	8.5945	–11.1715
264	Octanal	$C_8H_{16}O$	124-13-0	128.212	–29.02	–8.377	5.0063	–4.74
265	Octane	C_8H_{18}	111-65-9	114.229	–20.875	1.6	4.6723	–5.07415
266	Octanoic acid	$C_8H_{16}O_2$	124-07-2	144.211	–55.6	–32.5	5.2	–4.448
267	1-Octanol	$C_8H_{18}O$	111-87-5	130.228	–35.73	–11.7	5.187	–4.895
268	2-Octanol	$C_8H_{18}O$	123-96-6	130.228	–37.62	–13.43	5.132	–4.894
269	2-Octanone	$C_8H_{16}O$	111-13-7	128.212	–32.16	–11.38	4.962	–4.6984
270	3-Octanone	$C_8H_{16}O$	106-68-3	128.212	–33.9	–12.81	4.879	–4.711
271	1-Octene	C_8H_{16}	111-66-0	112.213	–8.194	10.57	4.637	–4.961
272	Octyl mercaptan	$C_8H_{18}S$	111-88-6	146.294	–17.01	4.457	5.331	–5.3962
273	1-Octyne	C_8H_{14}	629-05-0	110.197	8.23	23.5	4.478	–4.88145
274	Oxalic acid	$C_2H_2O_4$	144-62-7	90.035	–72.37	–66.14	3.433	–0.1989
275	Oxygen	O_2	7782-44-7	31.999	0	0	2.05043	0
276	Ozone	O_3	10028-15-6	47.998	14.2671	16.3164	2.38823	–0.142671
277	Pentadecane	$C_{15}H_{32}$	629-62-9	212.415	–35.311	7.426	7.4181	–9.34237
278	Pentanal	$C_5H_{10}O$	110-62-3	86.132	–22.78	–10.71	3.8289	–2.91
279	Pentane	C_5H_{12}	109-66-0	72.149	–14.676	–0.8813	3.4945	–3.24494
280	Pentanoic acid	$C_5H_{10}O_2$	109-52-4	102.132	–49.13	–34.7	4.02	–2.617
281	1-Pentanol	$C_5H_{12}O$	71-41-0	88.148	–29.57	–14.23	4.01	–3.064
282	2-Pentanol	$C_5H_{12}O$	6032-29-7	88.148	–31.37	–15.88	3.958	–3.058
283	2-Pentanone	$C_5H_{10}O$	107-87-9	86.132	–25.92	–13.83	3.786	–2.87956
284	3-Pentanone	$C_5H_{10}O$	96-22-0	86.132	–25.79	–13.44	3.7	–2.8804
285	1-Pentene	C_5H_{10}	109-67-1	70.133	–2.162	7.837	3.462	–3.13037
286	2-Pentyl mercaptan	$C_5H_{12}S$	2084-19-7	104.214	–11.3	1.814	4.05	–3.564
287	Pentyl mercaptan	$C_5H_{12}S$	110-66-7	104.214	–10.84	1.94408	4.154	–3.5641
288	1-Pentyne	C_5H_8	627-19-0	68.117	14.44	21.03	3.298	–3.051
289	2-Pentyne	C_5H_8	627-21-4	68.117	12.89	19.45	3.3084	–3.0291
290	Phenanthrene	$C_{14}H_{10}$	85-01-8	178.229	20.12	30.219	3.945	–6.8282
291	Phenol	C_6H_6O	108-95-2	94.111	–9.6399	–3.2637	3.1481	–2.921
292	Phenyl isocyanate	C_7H_5NO	103-71-9	119.121	–1.454	4.87212	3.527	–3.298
293	Phthalic anhydride	$C_8H_4O_3$	85-44-9	148.116	–37.14	–30.7001	3.995	–3.1715
294	Propadiene	C_3H_4	463-49-0	40.064	19.05	20.08	2.439	–1.8563
295	Propane	C_3H_8	74-98-6	44.096	–10.468	–2.439	2.702	–2.04311
296	1-Propanol	C_3H_8O	71-23-8	60.095	–25.46	–15.99	3.226	–1.844
297	2-Propanol	C_3H_8O	67-63-0	60.095	–27.21	–17.52	3.175	–1.834
298	Propenylcyclohexene	C_9H_{14}	13511-13-2	122.207	4.677	20.85	4.233	–5.232
299	Propionaldehyde	C_3H_6O	123-38-6	58.079	–18.63	–12.46	3.044	–1.6857
300	Propionic acid	$C_3H_6O_2$	79-09-4	74.079	–47.99	–38.5	2.949	–1.395

TABLE 2-179 Enthalpies and Gibbs Energies of Formation, Entropies, and Net Enthalpies of Combustion of Inorganic and Organic Compounds at 298.15 K (*Concluded*)

Cmpd. no.	Name	Formula	CAS no.	Mol. wt.	Ideal gas enthalpy of formation, J/kmol × 1E-07	Ideal gas Gibbs energy of formation, J/kmol × 1E-07	Ideal gas entropy, J/(kmol·K) × 1E-05	Standard net enthalpy of combustion, J/kmol × 1E-09
301	Propionitrile	C_3H_5N	107-12-0	55.079	5.18	9.74949	2.8614	–1.8007
302	Propyl acetate	$C_5H_{10}O_2$	109-60-4	102.132	–46.48	–32.04	4.023	–2.672
303	Propyl amine	C_3H_9N	107-10-8	59.110	–7.05	4.17	3.242	–2.165
304	Propylbenzene	C_9H_{12}	103-65-1	120.192	0.79	13.76	4.0014	–4.95415
305	Propylene	C_3H_6	115-07-1	42.080	2.023	6.264	2.67	–1.9262
306	Propyl formate	$C_4H_8O_2$	110-74-7	88.105	–40.76	–29.36	3.678	–2.041
307	2-Propyl mercaptan	C_3H_8S	75-33-2	76.161	–7.59	–0.218	3.243	–2.3398
308	Propyl mercaptan	C_3H_8S	107-03-9	76.161	–6.75	0.2583	3.365	–2.3458
309	1,2-Propylene glycol	$C_3H_8O_2$	57-55-6	76.094	–42.15	–30.4	3.52	–1.6476
310	Quinone	$C_6H_4O_2$	106-51-4	108.095	–12.29	–6.92	3.205	–2.658
311	Silicon tetrafluoride	F_4Si	7783-61-1	104.079	–161.494	–157.27	2.82651	0.7055
312	Styrene	C_8H_8	100-42-5	104.149	14.74	21.39	3.451	–4.219
313	Succinic acid	$C_4H_6O_4$	110-15-6	118.088	–82.29	–69.73	4.034	–1.3591
314	Sulfur dioxide	O_2S	7446-09-5	64.064	–29.684	–30.012	2.481	
315	Sulfur hexafluoride	F_6S	2551-62-4	146.055	–122.047	–111.653	2.91625	0.924
316	Sulfur trioxide	O_3S	7446-11-9	80.063	–39.572	–37.095	2.5651	0.1422
317	Terephthalic acid	$C_8H_6O_4$	100-21-0	166.131	–71.79	–59.9	4.48	–3.0576
318	*o*-Terphenyl	$C_{18}H_{14}$	84-15-1	230.304	27.66	42.3	5.263	–9.053
319	Tetradecane	$C_{14}H_{30}$	629-59-4	198.388	–33.244	6.599	7.0259	–8.73282
320	Tetrahydrofuran	C_4H_8O	109-99-9	72.106	–18.418	–7.969	2.9729	–2.325
321	1,2,3,4-Tetrahydronaphthalene	$C_{10}H_{12}$	119-64-2	132.202	2.661	16.71	3.6964	–5.3575
322	Tetrahydrothiophene	C_4H_8S	110-01-0	88.171	–3.376	4.59	3.1	–2.76549
323	2,2,3,3-Tetramethylbutane	C_8H_{18}	594-82-1	114.229	–22.56	2.239	3.893	–5.0639
324	Thiophene	C_4H_4S	110-02-1	84.140	11.544	12.67	2.784	–2.4352
325	Toluene	C_7H_8	108-88-3	92.138	5.017	12.22	3.2099	–3.734
326	1,1,2-Trichloroethane	$C_2H_3Cl_3$	79-00-5	133.404	–14.2	–8.097	3.371	–0.9685
327	Tridecane	$C_{13}H_{28}$	629-50-5	184.361	–31.177	5.771	6.6337	–8.1229
328	Triethyl amine	$C_6H_{15}N$	121-44-8	101.190	–9.58	11.41	4.054	–4.0405
329	Trimethyl amine	C_3H_9N	75-50-3	59.110	–2.431	9.899	2.87	–2.2449
330	1,2,3-Trimethylbenzene	C_9H_{12}	526-73-8	120.192	–0.95	12.61	3.805	–4.934
331	1,2,4-Trimethylbenzene	C_9H_{12}	95-63-6	120.192	–1.38	11.71	3.961	–4.9307
332	2,2,4-Trimethylpentane	C_8H_{18}	540-84-1	114.229	–22.401	1.394	4.2296	–5.06528
333	2,3,3-Trimethylpentane	C_8H_{18}	560-21-4	114.229	–21.845	1.828	4.2702	–5.06876
334	1,3,5-Trinitrobenzene	$C_6H_3N_3O_6$	99-35-4	213.105	6.24	26.79	4.435	–2.6867
335	2,4,6-Trinitrotoluene	$C_7H_5N_3O_6$	118-96-7	227.131	4.34	28.44	4.607	–3.2959
336	Undecane	$C_{11}H_{24}$	1120-21-4	156.308	–27.043	4.116	5.8493	–6.9036
337	1-Undecanol	$C_{11}H_{24}O$	112-42-5	172.308	–41.9	–9.177	6.363	–6.726
338	Vinyl acetate	$C_4H_6O_2$	108-05-4	86.089	–31.49	–22.79	3.28	–1.95
339	Vinyl acetylene	C_4H_4	689-97-4	52.075	30.46	30.6	2.794	–2.362
340	Vinyl chloride	C_2H_3Cl	75-01-4	62.498	2.845	4.195	2.7354	–1.178
341	Vinyl trichlorosilane	$C_2H_3Cl_3Si$	75-94-5	161.490	–48.116	–42.5514	3.73966	–1.544
342	Water	H_2O	7732-18-5	18.015	–24.1814	–22.859	1.88724	
343	*m*-Xylene	C_8H_{10}	108-38-3	106.165	1.732	11.876	3.5854	–4.3318
344	*o*-Xylene	C_8H_{10}	95-47-6	106.165	1.908	12.2	3.5383	–4.333
345	*p*-Xylene	C_8H_{10}	106-42-3	106.165	1.803	12.14	3.52165	–4.333

The compounds are considered to be formed from the elements in their standard states at 298.15 K and 101,325 Pa. These include C (graphite) and S (rhombic). Enthalpy of combustion is the net value for the compound in its standard state at 298.15 K and 101,325 Pa. Products of combustion are taken to be CO_2 (gas), H_2O (gas), Cl_2 (gas), Br_2 (gas), I_2 (gas), SO_2 (gas), N_2 (gas), P_4O_{10} (crystalline), SiO_2 (crystobalite), and Al_2O_3 (crystal, alpha).