THERMODYNAMIC PROPERTIES OF AQUEOUS IONS

This table contains standard state thermodynamic properties of positive and negative ions in aqueous solution. It includes enthalpy and Gibbs energy of formation, entropy, and heat capacity, and thus serves as a companion to the preceding table, "Standard Thermodynamic Properties of Chemical Substances". The standard state is the hypothetical ideal solution with molality m = 1 mol/kg (mean ionic molality $m_{\pm}$ in the case of a species which is assumed to dissociate at infinite dilution). Further details on conventions may be found in Reference 1.

All values refer to standard conditions of 25 °C and 100 kPa pressure.

References

1. Wagman, D. D., Evans, W. H., Parker, V. B., Schumm, R. H., Halow, I., Bailey, S. M., Churney, K. L., and Nuttall, R. L., *The NBS Tables of Chemical Thermodynamic Properties, J. Phys. Chem. Ref. Data*, Vol. 11, Suppl. 2, 1982.
2. Zemaitis, J. F., Clark, D. M., Rafal, M., and Scrivner, N. C., *Handbook of Aqueous Electrolyte Thermodynamics*, American Institute of Chemical Engineers, New York, 1986.

Species	$\Delta_f H°$/ kJ mol^{-1}	$\Delta_f G°$/ kJ mol^{-1}	$S°$/ J mol^{-1}K^{-1}	C_p/ J mol^{-1}K^{-1}
Cations				
Ag^{+}	105.6	77.1	72.7	21.8
Al^{+3}	−531.0	−485.0	−321.7	
$AlOH^{+2}$		−694.1		
Ba^{+2}	−537.6	−560.8	9.6	
$BaOH^{+}$		−730.5		
Be^{+2}	−382.8	−379.7	−129.7	
Bi^{+3}		82.8		
$BiOH^{+2}$		−146.4		
Ca^{+2}	−542.8	−553.6	−53.1	
$CaOH^{+}$		−718.4		
Cd^{+2}	−75.9	−77.6	−73.2	
$CdOH^{+}$		−261.1		
Ce^{+3}	−696.2	−672.0	−205.0	
Ce^{+4}	−537.2	−503.8	−301.0	
Co^{+2}	−58.2	−54.4	−113.0	
Co^{+3}	92.0	134.0	−305.0	
Cr^{+2}	−143.5			
Cs^{+}	−258.3	−292.0	133.1	−10.5
Cu^{+}	71.7	50.0	40.6	
Cu^{+2}	64.8	65.5	−99.6	
Dy^{+3}	−699.0	−665.0	−231.0	21.0
Er^{+3}	−705.4	−669.1	−244.3	21.0
Eu^{+2}	−527.0	−540.2	−8.0	
Eu^{+3}	−605.0	−574.1	−222.0	8.0
Fe^{+2}	−89.1	−78.9	−137.7	
Fe^{+3}	−48.5	−4.7	−315.9	
$FeOH^{+}$	−324.7	−277.4	−29.0	
$FeOH^{+2}$	−290.8	−229.4	−142.0	
$Fe(OH)_2^{+}$		−438.0		
Ga^{+2}		−88.0		
Ga^{+3}	−211.7	−159.0	−331.0	
$GaOH^{+2}$		−380.3		
$Ga(OH)_2^{+}$		−597.4		
Gd^{+3}	−686.0	−661.0	−205.9	
H^{+}	0	0	0	0
Hg^{+2}	171.1	164.4	−32.2	
Hg_2^{+2}	172.4	153.5	84.5	
$HgOH^{+}$	−84.5	−52.3	71.0	
Ho^{+3}	−705.0	−673.7	−226.8	17.0
In^{+}		−12.1		
In^{+2}		−50.7		
In^{+3}	−105.0	−98.0	−151.0	
$InOH^{+2}$	−370.3	−313.0	−88.0	
$In(OH)_2^{+}$	−619.0	−525.0	25.0	
K^{+}	−252.4	−283.3	102.5	21.8
La^{+3}	−707.1	−683.7	−217.6	−13.0
Li^{+}	−278.5	−293.3	13.4	68.6
Lu^{+3}	−665.0	−628.0	−264.0	25.0
LuF^{+2}		−931.4		
Mg^{+2}	−466.9	−454.8	−138.1	
$MgOH^{+}$		−626.7		
Mn^{+2}	−220.8	−228.1	−73.6	50.0
$MnOH^{+}$	−450.6	−405.0	−17.0	
NH_4^{+}	−132.5	−79.3	113.4	79.9
$N_2H_5^{+}$	−7.5	82.5	151.0	70.3
Na^{+}	−240.1	−261.9	59.0	46.4
Nd^{+3}	−696.2	−671.6	−206.7	−21.0
Ni^{+2}	−54.0	−45.6	−128.9	
$NiOH^{+}$	−287.9	−227.6	−71.0	
PH_4^{+}		92.1		
Pa^{+4}	−619.0			
Pb^{+2}	−1.7	−24.4	10.5	
$PbOH^{+}$		−226.3		
Pd^{+2}	149.0	176.5	−184.0	
Po^{+2}		71.0		
Po^{+4}		293.0		
Pr^{+3}	−704.6	−679.1	−209.0	−29.0
Pt^{+2}		254.8		
Ra^{+2}	−527.6	−561.5	54.0	
Rb^{+}	−251.2	−284.0	121.5	
Re^{+}		−33.0		
Sc^{+3}	−614.2	−586.6	−255.0	
$ScOH^{+2}$	−861.5	−801.2	−134.0	
Sm^{+2}		−497.5		
Sm^{+3}	−691.6	−666.6	−211.7	−21.0
Sn^{+2}	−8.8	−27.2	−17.0	
$SnOH^{+}$	−286.2	−254.8	50.0	
Sr^{+2}	−545.8	−559.5	−32.6	
$SrOH^{+}$		−721.3		
Tb^{+3}	−682.8	−651.9	−226.0	17.0
$Te(OH)_3^{+}$	−608.4	−496.1	111.7	
Th^{+4}	−769.0	−705.1	−422.6	
$Th(OH)^{+3}$	−1030.1	−920.5	−343.0	
$Th(OH)_2^{+2}$	−1282.4	−1140.9	−218.0	
Tl^{+}	5.4	−32.4	125.5	

Species	$\Delta_f H°$/ kJ mol^{-1}	$\Delta_f G°$/ kJ mol^{-1}	$S°$/ J mol^{-1}K^{-1}	C_p/ J mol^{-1}K^{-1}
Tl^{+3}	196.6	214.6	−192.0	
$TlOH^{+2}$		−15.9		
$Tl(OH)_2^{+}$		−244.7		
Tm^{+3}	−697.9	−662.0	−243.0	25.0
U^{+3}	−489.1	−476.2	−188.0	
U^{+4}	−591.2	−531.9	−410.0	
Y^{+3}	−723.4	−693.8	−251.0	
$Y_2(OH)_2^{+4}$		−1780.3		
Yb^{+2}		−527.0		
Yb^{+3}	−674.5	−644.0	−238.0	25.0
$Y(OH)^{+2}$		−879.1		
Zn^{+2}	−153.9	−147.1	−112.1	46.0
$ZnOH^{+}$		−330.1		
Anions				
AlO_2^{-}	−930.9	−830.9	−36.8	
$Al(OH)_4^{-}$	−1502.5	−1305.3	102.9	
AsO_2^{-}	−429.0	−350.0	40.6	
AsO_4^{-3}	−888.1	−648.4	−162.8	
BF_4^{-}	−1574.9	−1486.9	180.0	
BH_4^{-}	48.2	114.4	110.5	
BO_2^{-}	−772.4	−678.9	−37.2	
$B_4O_7^{-2}$		−2604.8		
BeO_2^{-2}	−790.8	−640.1	−159.0	
Br^{-}	−121.6	−104.0	82.4	−141.8
BrO^{-}	−94.1	−33.4	42.0	
BrO_3^{-}	−67.1	18.6	161.7	
BrO_4^{-}	13.0	118.1	199.6	
$CHOO^{-}$	−425.6	−351.0	92.0	−87.9
CH_3COO^{-}	−486.0	−369.3	86.6	−6.3
$C_2O_4^{-2}$	−825.1	−673.9	45.6	
$C_2O_4H^{-}$	−818.4	−698.3	149.4	
Cl^{-}	−167.2	−131.2	56.5	−136.4
ClO^{-}	−107.1	−36.8	42.0	
ClO_2^{-}	−66.5	17.2	101.3	
ClO_3^{-}	−104.0	−8.0	162.3	
ClO_4^{-}	−129.3	−8.5	182.0	
CN^{-}	150.6	172.4	94.1	
CO_3^{-2}	−677.1	−527.8	−56.9	
CrO_4^{-2}	−881.2	−727.8	50.2	
$Cr_2O_7^{-2}$	−1490.3	−1301.1	261.9	
F^{-}	−332.6	−278.8	−13.8	−106.7
$Fe(CN)_6^{-3}$	561.9	729.4	270.3	
$Fe(CN)_6^{-4}$	455.6	695.1	95.0	
$HB_4O_7^{-}$		−2685.1		
HCO_3^{-}	−692.0	−586.8	91.2	
HF_2^{-}	−649.9	−578.1	92.5	
HPO_3F^{-}		−1198.2		
HPO_4^{-2}	−1292.1	−1089.2	−33.5	
$HP_2O_7^{-3}$	−2274.8	−1972.2	46.0	
HS^{-}	−17.6	12.1	62.8	
HSO_3^{-}	−626.2	−527.7	139.7	
HSO_4^{-}	−887.3	−755.9	131.8	−84.0
$HS_2O_4^{-}$		−614.5		
HSe^{-}	15.9	44.0	79.0	
$HSeO_3^{-}$	−514.6	−411.5	135.1	
$HSeO_4^{-}$	−581.6	−452.2	149.4	
$H_2AsO_3^{-}$	−714.8	−587.1	110.5	
$H_2AsO_4^{-}$	−909.6	−753.2	117.0	
$H_2PO_4^{-}$	−1296.3	−1130.2	90.4	
$H_2P_2O_7^{-2}$	−2278.6	−2010.2	163.0	
I^{-}	−55.2	−51.6	111.3	−142.3
IO^{-}	−107.5	−38.5	−5.4	
IO_3^{-}	−221.3	−128.0	118.4	
IO_4^{-}	−151.5	−58.5	222.0	
MnO_4^{-}	−541.4	−447.2	191.2	−82.0
MnO_4^{-2}	−653.0	−500.7	59.0	
MoO_4^{-2}	−997.9	−836.3	27.2	
NO_2^{-}	−104.6	−32.2	123.0	−97.5
NO_3^{-}	−207.4	−111.3	146.4	−86.6
N_3^{-}	275.1	348.2	107.9	
OCN^{-}	−146.0	−97.4	106.7	
OH^{-}	−230.0	−157.2	−10.8	−148.5
PO_4^{-3}	−1277.4	−1018.7	−220.5	
$P_2O_7^{-4}$	−2271.1	−1919.0	−117.0	
Re^{-}	46.0	10.1	230.0	
S^{-2}	33.1	85.8	−14.6	
SCN^{-}	76.4	92.7	144.3	−40.2
SO_3^{-2}	−635.5	−486.5	−29.0	
SO_4^{-2}	−909.3	−744.5	20.1	−293.0
S_2^{-2}	30.1	79.5	28.5	
$S_2O_3^{-2}$	−652.3	−522.5	67.0	
$S_2O_4^{-2}$	−753.5	−600.3	92.0	
$S_2O_8^{-2}$	−1344.7	−1114.9	244.3	
Se^{-2}		129.3		
SeO_3^{-2}	−509.2	−369.8	13.0	
SeO_4^{-2}	−599.1	−441.3	54.0	
VO_3^{-}	−888.3	−783.6	50.0	
VO_4^{-3}		−899.0		
WO_4^{-2}	−1075.7			