CH 223 Spring 2025:

Problem Set #5

Instructions

Step One (all sections):

- **Learn the material** for Problem Set #5 by **reading Chapter 16 and Chapter 17** of the textbook and/or by watching the videos found on our website (https://mhchem.org/223)
- **Try the problems** for Problem Set #5 found on the next pages on your own first. **Write out the answers (and show your work) by hand (on a tablet or paper)**; do not type your answers (and work) to avoid a point penalty. If you write the answers on the problem set itself, you will receive fewer points. Include your name on your problem set!

Step Two:

Section 01 and H1: We will go over Problem Set #5 during recitation. ***Self correct all problems*** of your problem set before turning it in at the end of recitation.

- *Section 01:* due **Monday, May 19 at 1:10 PM**
- *Section H1:* due **Wednesday, May 21 at 1:10 PM**

Section W1: **Watch the recitation video** for Problem Set #5:

http://mhchem.org/v/t.htm

- **Self correct *all* of the problems** while viewing the video. Mark correct problems with a star (or other similar mark), and correct all incorrect problems (show the correct answer and the steps required to achieve it.)
- **Submit Problem Set #5 via email (mike.russell@mhcc.edu) as a single PDF file** (use CamScanner (https://camscanner.com), CombinePDF (https://combinepdf.com), etc.) **by 11:59 PM Wednesday, May 21.**

If you have any questions regarding this assignment, please email (mike.russell@mhcc.edu) the instructor! Good luck on this assignment!

CH 223 Problem Set #5

** Complete problem set on separate pieces of paper showing all work, circling final answers, etc.*
** Self correct your work before turning it in to the instructor.*

Covering: **Chapter Sixteen, Chapter Seventeen** *and* **Chapter Guide Five**
Important Tables and/or Constants: **F = 96485 C/mol e$^-$, R = 8.3145 J mol^{-1} K^{-1}**, "**Redox Reactions**" *(Handout),* **Table of Redox Potentials** *at the end of this problem set,* **Table of Thermodynamic values** *at the end of this problem set and here:* **http://mhchem.org/thermo**

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1. Classify each of the reactions according to their spontaneity. Are these reactions enthalpy and/or entropy driven?
   a. $C_6H_{12}O_6(s) + 6\ O_2(g) \rightarrow 6\ CO_2(g) + 6\ H_2O(\ell)$ $\Delta H° = -673$ kJ $\Delta S° = 60.4$ J/K
   b. $MgO(s) + C(\text{graphite}) \rightarrow Mg(s) + CO(g)$ $\Delta H° = 490.7$ kJ $\Delta S° = 197.9$ J/K
2. Use a Table to calculate $\Delta H°$ and $\Delta S°$ for the reaction of silicon(IV) oxide with carbon:
   $$SiO_2(s) + C(\text{graphite}) \rightarrow Si(s) + CO_2(g)$$
   a. Is the reaction spontaneous at 298 K?
   b. Is the reaction predicted to be spontaneous at higher temperatures?
3. Using values of $\Delta H°_f$ and $S°$, calculate $\Delta G°_{rxn}$ for each of the following reactions. Which of these reactions is (are) predicted to be product-favored? Are the reactions enthalpy or entropy driven?
   a. $Ba(s) + 2\ H_2O(\ell) \rightarrow Ba(OH)_2(aq) + 2\ H_2(g)$
      (*Note:* for $Ba(OH)_2(aq)$, $\Delta H° = -1002.82$ kJ/mol and $S° = 74.5$ J K^{-1} mol^{-1})
   b. $6\ C(\text{graphite}) + 3\ H_2(g) \rightarrow C_6H_6(\ell)$
4. Using values of $\Delta G°_f$, calculate $\Delta G°_{rxn}$ for each of the following reactions. Which are product-favored?
   a. $HgS(s, \text{red}) + O_2(g) \rightarrow Hg(\ell) + SO_2(g)$
   b. $2\ H_2S(g) + 3\ O_2(g) \rightarrow 2\ H_2O(g) + 2\ SO_2(g)$
5. Estimate the temperature required to decompose $CaSO_4(s)$ into $CaO(s)$ and $SO_3(g)$ using values of $\Delta H°_f$ and $S°$.
6. The formation of $O_3(g)$ from $O_2(g)$ has a standard free energy change, $\Delta G°$, of +163.2 kJ/mol at 25 °C. Calculate K_p at this temperature. Comment on the connection between the sign of $\Delta G°$ and the magnitude of K_p.
7. Write balanced equations for the following half-reactions. Specify whether each is an oxidation or reduction.
   a. $H_2C_2O_4(aq) \rightarrow CO_2(g)$ (in acid)
   b. $NO_3^{-1}(aq) \rightarrow NO(g)$ (in acid)
   c. $MnO_4^{-1}(aq) \rightarrow MnO_2(s)$ (in base)
8. Balance the following redox equations. All occur in acid solution.
   a. $Sn(s) + H^+(aq) \rightarrow Sn^{2+}(aq) + H_2(g)$
   b. $Cr_2O_7^{2-}(aq) + Fe^{2+}(aq) \rightarrow Cr^{3+}(aq) + Fe^{3+}(aq)$

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9. Balance the following redox reactions. All occur in basic solution.
    a. $NiO_2(s) + Zn(s) \rightarrow Ni(OH)_2(s) + Zn(OH)_2(s)$
    b. $Fe(OH)_2(s) + CrO_4^{2-}(aq) \rightarrow Fe(OH)_3(s) + [Cr(OH)_4]^{-1}$
10. The following **voltaic** cell is created: $Ag(s) \mid Ag^+(aq) \parallel Cl_2(g, 1\ atm) \mid Cl^{-1}(aq, 1.0\ M) \mid Pt(s)$
    a. Write equations for the oxidation and reduction half-reactions and for the overall (cell) reaction.
    b. Which half-reaction occurs in the anode compartment and which occurs in the cathode compartment?
    c. Complete the following sentences: Electrons in the external circuit flow from the _____ electrode to the _____ electrode. Negative ions move in the salt bridge from the _____ half-cell to the _____ half-cell.
11. Balance each of the following unbalanced equations, then calculate the standard reduction potential, $E°$, and decide whether each is product-favored as written. All reactions occur in acidic solution.
    a. $Fe^{2+}(aq) + Cu^{2+}(aq) \rightarrow Cu(s) + Fe^{3+}(aq)$
    b. $MnO_4^{-1}(aq) + NO(g) \rightarrow Mn^{2+}(aq) + NO_3^{-1}(aq)$
12. Calculate the potential at 298 K developed by a voltaic cell using the following reaction if all dissolved species are 0.015 M: (hint: use the Nernst equation!)

$$2\ Fe^{2+}(aq) + H_2O_2(aq) + 2\ H^+(aq) \rightarrow 2\ Fe^{3+}(aq) + 2\ H_2O(\ell)$$

13. Calculate $\Delta G°$ and the equilibrium constant for the following reaction:

$$Cu(s) + 2\ Ag^+(aq) \rightarrow Cu^{2+}(aq) + 2\ Ag(s)$$

14. In the electrolysis of a solution containing $Ag^+(aq)$, metallic Ag(s) deposits on the cathode. Using a current of 1.12 A for 2.40 h, what mass of silver forms?

Standard Reduction Potentials in Aqueous Solution at 25 °C

Reduction Half-Reaction		$E°$ (V)
$F_2(g) + 2\ e^-$	$\longrightarrow 2\ F^-(aq)$	+2.87
$H_2O_2(aq) + 2\ H^+(aq) + 2\ e^-$	$\longrightarrow 2\ H_2O(\ell)$	+1.77
$PbO_2(s) + SO_4^{2-}(aq) + 4\ H^+(aq) + 2\ e^-$	$\longrightarrow PbSO_4(s) + 2\ H_2O(\ell)$	+1.685
$MnO_4^-(aq) + 8\ H^+(aq) + 5\ e^-$	$\longrightarrow Mn^{2+}(aq) + 4\ H_2O(\ell)$	+1.51
$Au^{3+}(aq) + 3\ e^-$	$\longrightarrow Au(s)$	+1.50
$Cl_2(g) + 2\ e^-$	$\longrightarrow 2\ Cl^-(aq)$	+1.36
$Cr_2O_7^{2-}(aq) + 14\ H^+(aq) + 6\ e^-$	$\longrightarrow 2\ Cr^{3+}(aq) + 7\ H_2O\ (\ell)$	+1.33
$O_2(g) + 4\ H^+(aq) + 4\ e^-$	$\longrightarrow 2\ H_2O(\ell)$	+1.229
$Br_2(\ell) + 2\ e^-$	$\longrightarrow 2\ Br^-(aq)$	+1.08
$NO_3^-(aq) + 4\ H^+(aq) + 3\ e^-$	$\longrightarrow NO(g) + 2\ H_2O(\ell)$	+0.96
$OCl^-(aq) + H_2O(\ell) + 2\ e^-$	$\longrightarrow Cl^-(aq) + 2\ OH^-(aq)$	+0.89
$Hg^{2+}(aq) + 2\ e^-$	$\longrightarrow Hg(\ell)$	+0.855
$Ag^+(aq) + e^-$	$\longrightarrow Ag(s)$	+0.799
$Hg_2^{2+}(aq) + 2\ e^-$	$\longrightarrow 2\ Hg(\ell)$	+0.789
$Fe^{3+}(aq) + e^-$	$\longrightarrow Fe^{2+}(aq)$	+0.771
$I_2(s) + 2\ e^-$	$\longrightarrow 2\ I^-(aq)$	+0.535
$O_2(g) + 2\ H_2O(\ell) + 4\ e^-$	$\longrightarrow 4\ OH^-(aq)$	+0.40
$Cu^{2+}(aq) + 2\ e^-$	$\longrightarrow Cu(s)$	+0.337
$Sn^{4+}(aq) + 2\ e^-$	$\longrightarrow Sn^{2+}(aq)$	+0.15
$2\ H^+(aq) + 2\ e^-$	$\longrightarrow H_2(g)$	0.00
$Sn^{2+}(aq) + 2\ e^-$	$\longrightarrow Sn(s)$	−0.14
$Ni^{2+}(aq) + 2\ e^-$	$\longrightarrow Ni(s)$	−0.25
$V^{3+}(aq) + e^-$	$\longrightarrow V^{2+}(aq)$	−0.255
$PbSO_4(s) + 2\ e^-$	$\longrightarrow Pb(s) + SO_4^{2-}(aq)$	−0.356
$Cd^{2+}(aq) + 2\ e^-$	$\longrightarrow Cd(s)$	−0.40
$Fe^{2+}(aq) + 2\ e^-$	$\longrightarrow Fe(s)$	−0.44
$Zn^{2+}(aq) + 2\ e^-$	$\longrightarrow Zn(s)$	−0.763
$2\ H_2O(\ell) + 2\ e^-$	$\longrightarrow H_2(g) + 2\ OH^-(aq)$	−0.8277
$Al^{3+}(aq) + 3\ e^-$	$\longrightarrow Al(s)$	−1.66
$Mg^{2+}(aq) + 2\ e^-$	$\longrightarrow Mg(s)$	−2.37
$Na^+(aq) + e^-$	$\longrightarrow Na(s)$	−2.714
$K^+(aq) + e^-$	$\longrightarrow K(s)$	−2.925
$Li^+(aq) + e^-$	$\longrightarrow Li(s)$	−3.045

Increasing strength of oxidizing agents

Increasing strength of reducing agents

* In volts (V) versus the standard hydrogen electrode.

Standard Thermodynamic Properties for Selected Substances

Substance	$\Delta H°_f$ (kJ/mol)	$\Delta G°_f$ (kJ/mol)	$S°$ (J/K•mol)
aluminum			
Al(*s*)	0	0	28.3
Al(*g*)	324.4	285.7	164.54
Al_2O_3(*s*)	–1676	–1582	50.92
AlF_3(*s*)	–1510.4	–1425	66.5
$AlCl_3$(*s*)	–704.2	–628.8	110.67
$AlCl_3 \cdot 6H_2O$(*s*)	–2691.57	–2269.40	376.56
Al_2S_3(*s*)	–724.0	–492.4	116.9
$Al_2(SO_4)_3$(*s*)	–3445.06	–3506.61	239.32
antimony			
Sb(*s*)	0	0	45.69
Sb(*g*)	262.34	222.17	180.16
Sb_4O_6(*s*)	–1440.55	–1268.17	220.92
$SbCl_3$(*g*)	–313.8	–301.2	337.80
$SbCl_5$(*g*)	–394.34	–334.29	401.94
Sb_2S_3(s)	–174.89	–173.64	182.00
$SbCl_3$(s)	–382.17	–323.72	184.10
SbOCl(s)	–374.0	-	-
arsenic			
As(*s*)	0	0	35.1
As(*g*)	302.5	261.0	174.21
As_4(*g*)	143.9	92.4	314
As_4O_6(*s*)	–1313.94	–1152.52	214.22
As_2O_5(*s*)	–924.87	–782.41	105.44
$AsCl_3$(*g*)	–261.50	–248.95	327.06
As_2S_3(*s*)	–169.03	–168.62	163.59
AsH_3(*g*)	66.44	68.93	222.78
H_3AsO_4(*s*)	–906.3	—	—
barium			
Ba(*s*)	0	0	62.5
Ba(*g*)	180	146	170.24
BaO(*s*)	–548.0	–520.3	72.1
$BaCl_2$(*s*)	–855.0	–806.7	123.7
$BaSO_4$(*s*)	–1473.2	–1362.3	132.2
beryllium			
Be(*s*)	0	0	9.50
Be(*g*)	324.3	286.6	136.27
BeO(*s*)	–609.4	–580.1	13.8
bismuth			
Bi(*s*)	0	0	56.74
Bi(*g*)	207.1	168.2	187.00
Bi_2O_3(*s*)	–573.88	–493.7	151.5
$BiCl_3$(*s*)	–379.07	–315.06	176.98
Bi_2S_3(*s*)	–143.1	–140.6	200.4
boron			
B(*s*)	0	0	5.86
B(*g*)	565.0	521.0	153.4
B_2O_3(*s*)	–1273.5	–1194.3	53.97
B_2H_6(*g*)	36.4	87.6	232.1
H_3BO_3(*s*)	–1094.33	–968.92	88.83
BF_3(*g*)	–1136.0	–1119.4	254.4
BCl_3(*g*)	–403.8	–388.7	290.1
$B_3N_3H_6$(*l*)	–540.99	–392.79	199.58

Standard Thermodynamic Properties for Selected Substances

Substance	$\Delta H°_f$ (kJ/mol)	$\Delta G°_f$ (kJ/mol)	$S°$ (J/K•mol)
boron *continued*			
$HBO_2(s)$	–794.25	–723.41	37.66
bromine			
$Br_2(l)$	0	0	152.23
$Br_2(g)$	30.91	3.142	245.5
$Br(g)$	111.88	82.429	175.0
$BrF_3(g)$	–255.60	–229.45	292.42
$HBr(g)$	–36.3	–53.43	198.7
cadmium			
$Cd(s)$	0	0	51.76
$Cd(g)$	112.01	77.41	167.75
$CdO(s)$	–258.2	–228.4	54.8
$CdCl_2(s)$	–391.5	–343.9	115.3
$CdSO_4(s)$	–933.3	–822.7	123.0
$CdS(s)$	–161.9	–156.5	64.9
calcium			
$Ca(s)$	0	0	41.6
$Ca(g)$	178.2	144.3	154.88
$CaO(s)$	–634.9	–603.3	38.1
$Ca(OH)_2(s)$	–985.2	–897.5	83.4
$CaSO_4(s)$	–1434.5	–1322.0	106.5
$CaSO_4 \cdot 2H_2O(s)$	–2022.63	–1797.45	194.14
$CaCO_3(s)$ (calcite)	–1220.0	–1081.4	110.0
$CaSO_3 \cdot H_2O(s)$	–1752.68	–1555.19	184.10
carbon			
$C(s)$ (graphite)	0	0	5.740
$C(s)$ (diamond)	1.89	2.90	2.38
$C(g)$	716.681	671.2	158.1
$CO(g)$	–110.52	–137.15	197.7
$CO_2(g)$	–393.51	–394.36	213.8
$CH_4(g)$	–74.6	–50.5	186.3
$CH_3OH(l)$	–239.2	–166.6	126.8
$CH_3OH(g)$	–201.0	–162.3	239.9
$CCl_4(l)$	–128.2	–62.5	214.4
$CCl_4(g)$	–95.7	–58.2	309.7
$CHCl_3(l)$	–134.1	–73.7	201.7
$CHCl_3(g)$	–103.14	–70.34	295.71
$CS_2(l)$	89.70	65.27	151.34
$CS_2(g)$	116.9	66.8	238.0
$C_2H_2(g)$	227.4	209.2	200.9
$C_2H_4(g)$	52.4	68.4	219.3
$C_2H_6(g)$	–84.0	–32.0	229.2
$CH_3CO_2H(l)$	–484.3	–389.9	159.8
$CH_3CO_2H(g)$	–434.84	–376.69	282.50
$C_2H_5OH(l)$	–277.6	–174.8	160.7
$C_2H_5OH(g)$	–234.8	–167.9	281.6
$C_3H_8(g)$	–103.8	–23.4	270.3
$C_6H_6(g)$	82.927	129.66	269.2
$C_6H_6(l)$	49.1	124.50	173.4
$CH_2Cl_2(l)$	–124.2	–63.2	177.8
$CH_2Cl_2(g)$	–95.4	–65.90	270.2
$CH_3Cl(g)$	–81.9	–60.2	234.6

Standard Thermodynamic Properties for Selected Substances

Substance	$\Delta H°_f$ (kJ/mol)	$\Delta G°_f$ (kJ/mol)	$S°$ (J/K•mol)
carbon *continued*			
$C_2H_5Cl(l)$	–136.52	–59.31	190.79
$C_2H_5Cl(g)$	–112.17	–60.39	276.00
$C_2N_2(g)$	308.98	297.36	241.90
$HCN(l)$	108.9	125.0	112.8
$HCN(g)$	135.5	124.7	201.8
chlorine			
$Cl2(g)$	0	0	223.1
$Cl(g)$	121.3	105.70	165.2
$ClF(g)$	–54.48	–55.94	217.78
$ClF_3(g)$	–158.99	–118.83	281.50
$Cl_2O(g)$	80.3	97.9	266.2
$Cl_2O_7(l)$	238.1	—	—
$Cl_2O_7(g)$	272.0	—	—
$HCl(g)$	–92.307	–95.299	186.9
$HClO_4(l)$	–40.58	—	—
chromium			
$Cr(s)$	0	0	23.77
$Cr(g)$	396.6	351.8	174.50
$Cr_2O_3(s)$	–1139.7	–1058.1	81.2
$CrO_3(s)$	–589.5	—	—
$(NH_4)_2Cr_2O_7(s)$	–1806.7	—	—
cobalt			
$Co(s)$	0	0	30.0
$CoO(s)$	–237.9	–214.2	52.97
$Co_3O_4(s)$	–910.02	–794.98	114.22
$Co(NO_3)_2(s)$	–420.5	—	—
copper			
$Cu(s)$	0	0	33.15
$Cu(g)$	338.32	298.58	166.38
$CuO(s)$	–157.3	–129.7	42.63
$Cu_2O(s)$	–168.6	–146.0	93.14
$CuS(s)$	–53.1	–53.6	66.5
$Cu_2S(s)$	–79.5	–86.2	120.9
$CuSO_4(s)$	–771.36	–662.2	109.2
$Cu(NO_3)_2(s)$	–302.9	—	—
fluorine			
$F_2(g)$	0	0	202.8
$F(g)$	79.4	62.3	158.8
$F_2O(g)$	24.7	41.9	247.43
$HF(g)$	–273.3	–275.4	173.8
hydrogen			
$H_2(g)$	0	0	130.7
$H(g)$	217.97	203.26	114.7
$H_2O(l)$	–285.83	–237.1	70.0
$H_2O(g)$	–241.82	–228.59	188.8
$H_2O_2(l)$	–187.78	–120.35	109.6
$H_2O_2(g)$	–136.3	–105.6	232.7
$HF(g)$	–273.3	–275.4	173.8
$HCl(g)$	–92.307	–95.299	186.9
$HBr(g)$	–36.3	–53.43	198.7
$HI(g)$	26.48	1.70	206.59

Standard Thermodynamic Properties for Selected Substances

Substance	$\Delta H°_f$ (kJ/mol)	$\Delta G°_f$ (kJ/mol)	$S°$ (J/K•mol)
hydrogen *continued*			
$H_2S(g)$	–20.6	–33.4	205.8
$H_2Se(g)$	29.7	15.9	219.0
iodine			
$I_2(s)$	0	0	116.14
$I_2(g)$	62.438	19.3	260.7
$I(g)$	106.84	70.2	180.8
$IF(g)$	95.65	–118.49	236.06
$ICl(g)$	17.78	–5.44	247.44
$IBr(g)$	40.84	3.72	258.66
$IF_7(g)$	–943.91	–818.39	346.44
$HI(g)$	26.48	1.70	206.59
iron			
$Fe(s)$	0	0	27.3
$Fe(g)$	416.3	370.7	180.5
$Fe_2O_3(s)$	–824.2	–742.2	87.40
$Fe_3O_4(s)$	–1118.4	–1015.4	146.4
$Fe(CO)_5(l)$	–774.04	–705.42	338.07
$Fe(CO)_5(g)$	–733.87	–697.26	445.18
$FeCl_2(s)$	–341.79	–302.30	117.95
$FeCl_3(s)$	–399.49	–334.00	142.3
$FeO(s)$	–272.0	–255.2	60.75
$Fe(OH)_2(s)$	–569.0	–486.5	88.
$Fe(OH)_3(s)$	–823.0	–696.5	106.7
$FeS(s)$	–100.0	–100.4	60.29
$Fe_3C(s)$	25.10	20.08	104.60
lead			
$Pb(s)$	0	0	64.81
$Pb(g)$	195.2	162.	175.4
$PbO(s)$ (yellow)	–217.32	–187.89	68.70
$PbO(s)$ (red)	–218.99	–188.93	66.5
$Pb(OH)_2(s)$	–515.9	—	—
$PbS(s)$	–100.4	–98.7	91.2
$Pb(NO_3)_2(s)$	–451.9	—	—
$PbO_2(s)$	–277.4	–217.3	68.6
$PbCl_2(s)$	–359.4	–314.1	136.0
lithium			
$Li(s)$	0	0	29.1
$Li(g)$	159.3	126.6	138.8
$LiH(s)$	–90.5	–68.3	20.0
$LiOH(s)$	–487.5	–441.5	42.8
$LiF(s)$	–616.0	–587.5	35.7
$Li_2CO_3(s)$	–1216.04	–1132.19	90.17
manganese			
$Mn(s)$	0	0	32.0
$Mn(g)$	280.7	238.5	173.7
$MnO(s)$	–385.2	–362.9	59.71
$MnO_2(s)$	–520.03	–465.1	53.05
$Mn_2O_3(s)$	–958.97	–881.15	110.46
$Mn_3O_4(s)$	–1378.83	–1283.23	155.64
mercury			
$Hg(l)$	0	0	75.9

Standard Thermodynamic Properties for Selected Substances

Substance	$\Delta H°_f$ (kJ/mol)	$\Delta G°_f$ (kJ/mol)	$S°$ (J/K•mol)
mercury *continued*			
$Hg(g)$	61.4	31.8	175.0
$HgO(s)$ (red)	–90.83	–58.5	70.29
$HgO(s)$ (yellow)	–90.46	–58.43	71.13
$HgCl_2(s)$	–224.3	–178.6	146.0
$Hg_2Cl_2(s)$	–265.4	–210.7	191.6
$HgS(s)$ (red)	–58.16	–50.6	82.4
$HgS(s)$ (black)	–53.56	–47.70	88.28
$HgSO_4(s)$	–707.51	–594.13	0.00
nitrogen			
$N_2(g)$	0	0	191.6
$N(g)$	472.704	455.5	153.3
$NO(g)$	90.25	87.6	210.8
$NO_2(g)$	33.2	51.30	240.1
$N_2O(g)$	81.6	103.7	220.0
$N_2O_3(g)$	83.72	139.41	312.17
$N_2O_4(g)$	11.1	99.8	304.4
$N_2O_5(g)$	11.3	115.1	355.7
$NH_3(g)$	–45.9	–16.5	192.8
$N_2H_4(l)$	50.63	149.43	121.21
$N_2H_4(g)$	95.4	159.4	238.5
$NH_4NO_3(s)$	–365.56	–183.87	151.08
$NH_4Cl(s)$	–314.43	–202.87	94.6
$NH_4Br(s)$	–270.8	–175.2	113.0
$NH_4I(s)$	–201.4	–112.5	117.0
$NH_4NO_2(s)$	–256.5	—	—
$HNO_3(l)$	–174.1	–80.7	155.6
$HNO_3(g)$	–133.9	–73.5	266.9
oxygen			
$O_2(g)$	0	0	205.2
$O(g)$	249.17	231.7	161.1
$O_3(g)$	142.7	163.2	238.9
phosphorus			
$P_4(s)$	0	0	164.4
$P_4(g)$	58.91	24.4	280.0
$P(g)$	314.64	278.25	163.19
$PH_3(g)$	5.4	13.5	210.2
$PCl_3(g)$	–287.0	–267.8	311.78
$PCl_5(g)$	–374.9	–305.0	364.4
$P_4O_6(s)$	–1640.1	—	—
$P_4O_{10}(s)$	–2984.0	–2697.0	228.86
$HPO_3(s)$	–948.5	—	—
$H_3PO_2(s)$	–604.6	—	—
$H_3PO_3(s)$	–964.4	—	—
$H_3PO_4(s)$	–1279.0	–1119.1	110.50
$H_3PO_4(l)$	–1266.9	–1124.3	110.5
$H_4P_2O_7(s)$	–2241.0	—	—
$POCl_3(l)$	–597.1	–520.8	222.5
$POCl_3(g)$	–558.5	–512.9	325.5
potassium			
$K(s)$	0	0	64.7
$K(g)$	89.0	60.5	160.3

Standard Thermodynamic Properties for Selected Substances

Substance	$\Delta H°_f$ (kJ/mol)	$\Delta G°_f$ (kJ/mol)	$S°$ (J/K•mol)
potassium *continued*			
KF(*s*)	–576.27	–537.75	66.57
KCl(*s*)	–436.5	–408.5	82.6
silicon			
Si(*s*)	0	0	18.8
Si(*g*)	450.0	405.5	168.0
SiO_2(*s*)	–910.7	–856.3	41.5
SiH_4(*g*)	34.3	56.9	204.6
H_2SiO_3(*s*)	–1188.67	–1092.44	133.89
H_4SiO_4(*s*)	–1481.14	–1333.02	192.46
SiF_4(*g*)	–1615.0	–1572.8	282.8
$SiCl_4$(*l*)	–687.0	–619.8	239.7
$SiCl_4$(*g*)	–662.75	–622.58	330.62
SiC(*s, beta cubic*)	–73.22	–70.71	16.61
SiC(*s, alpha hexagonal*)	–71.55	–69.04	16.48
silver			
Ag(*s*)	0	0	42.55
Ag(*g*)	284.9	246.0	172.89
Ag_2O(*s*)	–31.05	–11.20	121.3
AgCl(*s*)	–127.0	–109.8	96.3
Ag_2S(*s*)	–32.6	–40.7	144.0
sodium			
Na(*s*)	0	0	51.3
Na(g)	107.5	77.0	153.7
Na_2O(*s*)	–414.2	–375.5	75.1
NaCl(*s*)	–411.2	–384.1	72.1
sulfur			
S_8(*s*) (rhombic)	0	0	256.8
S(*g*)	278.81	238.25	167.82
SO_2(*g*)	–296.83	–300.1	248.2
SO_3(*g*)	–395.72	–371.06	256.76
H_2S(*g*)	–20.6	–33.4	205.8
H_2SO_4(*l*)	–813.989	690.00	156.90
$H_2S_2O_7$(*s*)	–1273.6	—	—
SF_4(*g*)	–728.43	–684.84	291.12
SF_6(*g*)	–1220.5	–1116.5	291.5
SCl_2(*l*)	–50	—	—
SCl_2(*g*)	–19.7	—	—
S_2Cl_2(*l*)	–59.4	—	—
S_2Cl_2(*g*)	–19.50	–29.25	319.45
$SOCl_2$(*g*)	–212.55	–198.32	309.66
$SOCl_2$(*l*)	–245.6	—	—
SO_2Cl_2(*l*)	–394.1	—	—
SO_2Cl_2(g)	–354.80	–310.45	311.83
tin			
Sn(*s*)	0	0	51.2
Sn(*g*)	301.2	266.2	168.5
SnO(*s*)	–285.8	–256.9	56.5
SnO_2(*s*)	–577.6	–515.8	49.0
$SnCl_4$(*l*)	–511.3	–440.1	258.6
$SnCl_4$(*g*)	–471.5	–432.2	365.8

Standard Thermodynamic Properties for Selected Substances

Substance	$\Delta H°_f$ (kJ/mol)	$\Delta G°_f$ (kJ/mol)	$S°$ (J/K•mol)
titanium			
Ti(*s*)	0	0	30.7
Ti(*g*)	473.0	428.4	180.3
$TiO_2(s)$	–944.0	–888.8	50.6
$TiCl_4(l)$	–804.2	–737.2	252.4
$TiCl_4(g)$	–763.2	–726.3	353.2
tungsten			
W(*s*)	0	0	32.6
W(*g*)	849.4	807.1	174.0
$WO_3(s)$	–842.9	–764.0	75.9
zinc			
Zn(*s*)	0	0	41.6
Zn(*g*)	130.73	95.14	160.98
ZnO(*s*)	–350.5	–320.5	43.7
$ZnCl_2(s)$	–415.1	–369.43	111.5
ZnS(*s*)	–206.0	–201.3	57.7
$ZnSO_4(s)$	–982.8	–871.5	110.5
$ZnCO_3(s)$	–812.78	–731.57	82.42
complexes			
cis-$[Co(NH_3)_4(NO_2)_2]NO_3$	–898.7	—	—
trans-$[Co(NH_3)_4(NO_2)_2]NO_3$	–896.2	—	—
$NH_4[Co(NH_3)_2(NO_2)_4]$	–837.6	—	—
$[Co(NH_3)_6][Co(NH_3)_2(NO_2)_4]_3$	–2733.0	—	—
cis-$[Co(NH_3)_4Cl_2]Cl$	–874.9	—	—
trans-$[Co(NH_3)_4Cl_2]Cl$	–877.4	—	—
cis-$[Co(en)_2(NO_2)_2]NO_3$	–689.5	—	—
cis-$[Co(en)_2Cl_2]Cl$	–681.2	—	—
trans-$[Co(en)_2Cl_2]Cl$	–677.4	—	—
$[Co(en)_3](ClO_4)_3$	–762.7	—	—
$[Co(en)_3]Br_2$	–595.8	—	—
$[Co(en)_3]I_2$	–475.3	—	—
$[Co(en)_3]I_3$	–519.2	—	—
$[Co(NH_3)_6](ClO_4)_3$	–1034.7	–221.1	615
$[Co(NH_3)_5NO_2](NO_3)_2$	–1088.7	–412.9	331
$[Co(NH_3)_6](NO_3)_3$	–1282.0	–524.5	448
$[Co(NH_3)_5Cl]Cl_2$	–1017.1	–582.5	366.1
$[Pt(NH_3)_4]Cl_2$	–725.5	—	—
$[Ni(NH_3)_6]Cl_2$	–994.1	—	—
$[Ni(NH_3)_6]Br_2$	–923.8	—	—
$[Ni(NH_3)_6]I_2$	–808.3	—	—

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