

*CH 221 Fall 2021:*

# Problem Set #5

## *Instructions*

*Step One (all sections):*

**Learn the material** for Problem Set #5 by **reading Chapter 3 and Chapter 5** of the textbook and/or by watching the videos found on our website (<https://mhchem.org/221>)

**Try the problems** for Problem Set #5 found on the next pages on your own first. Use separate paper and write out your answers, showing all of your work. 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 the class on November 3.

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

**<http://mhchem.org/w/k.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](mailto:mike.russell@mhcc.edu)) as a single PDF file** (use CamScanner (<https://camscanner.com>), CombinePDF (<https://combinepdf.com>), etc.) **by 11:59 PM Wednesday, November 3.**

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

## CH 221 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 Three (3.3-3.4), Chapter Five and Chapter Guide Five**

Important Tables / Constants:  $C(\text{H}_2\text{O}) = 4.184 \text{ J g}^{-1} \text{ K}^{-1}$ ,  $\log_{10} x = \ln x / \ln 10$  and the *Thermodynamic Values* found after this problem set and here: <http://mhchem.org/thermo>

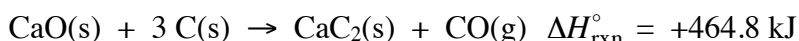
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- Determine the oxidation number of each element in the following ions or compounds.
  - $\text{O}_2(\text{g})$
  - $\text{CuO}$
  - $\text{UO}_2^{2+}$
  - $\text{H}_2\text{AsO}_4^{-1}$
  - $\text{OF}_2$
  - $\text{XeO}_4^{2-}$
- Which of the following reactions are oxidation-reduction reactions? Explain your answer briefly. Classify the remaining reactions.
  - $\text{CdCl}_2(\text{aq}) + \text{Na}_2\text{S}(\text{aq}) \rightarrow \text{CdS}(\text{s}) + 2 \text{NaCl}(\text{aq})$
  - $2 \text{Ca}(\text{s}) + \text{O}_2(\text{g}) \rightarrow 2 \text{CaO}(\text{s})$
  - $4 \text{Fe}(\text{OH})_2(\text{aq}) + 2 \text{H}_2\text{O}(\ell) + \text{O}_2(\text{g}) \rightarrow 4 \text{Fe}(\text{OH})_3(\text{aq})$
  - $\text{MgCO}_3(\text{s}) + 2 \text{HCl}(\text{aq}) \rightarrow \text{MgCl}_2(\text{aq}) + \text{H}_2\text{O}(\ell) + \text{CO}_2(\text{g})$
- In the following reactions, decide which reactant is oxidized and which is reduced. Designate the oxidizing agent and the reducing agent.
  - $\text{Cr}_2\text{O}_7^{2-}(\text{aq}) + 3 \text{Sn}^{2+}(\text{aq}) + 14 \text{H}^+(\text{aq}) \rightarrow 2 \text{Cr}^{3+}(\text{aq}) + 3 \text{Sn}^{4+}(\text{aq}) + 7 \text{H}_2\text{O}(\ell)$
  - $\text{FeS}(\text{s}) + 3 \text{NO}_3^{-1}(\text{aq}) + 4 \text{H}^+(\text{aq}) \rightarrow 3 \text{NO}(\text{g}) + \text{SO}_4^{2-}(\text{aq}) + \text{Fe}^{3+}(\text{aq}) + 2 \text{H}_2\text{O}(\ell)$
- What is the mass of solute, in grams, in 125 mL of a  $1.023 \times 10^{-3} \text{ M}$  solution of  $\text{Na}_3\text{PO}_4$ ? What are the molar concentrations of  $\text{Na}^+$  and  $\text{PO}_4^{3-}$  ions?
- Twelve (12.0) mL of a 0.125 M  $\text{BaCl}_2$  solution is diluted with 9.0 mL of water to a total volume of 21.0 mL. What is the concentration (M) of the new solution? What is the concentration (M) of  $\text{Cl}^{-1}$  in the final solution? How many grams of  $\text{BaCl}_2$  are in the final solution?
- A saturated solution of milk of magnesia,  $\text{Mg}(\text{OH})_2$ , has a pH of 10.5. What is the hydrogen ion concentration of the solution? Is the solution acidic or basic?
- What mass of  $\text{Na}_2\text{CO}_3$ , in grams, is required for complete reaction with 50.0 mL of 0.125 M  $\text{HNO}_3$ ?  
 $\text{Na}_2\text{CO}_3(\text{aq}) + 2 \text{HNO}_3(\text{aq}) \rightarrow 2 \text{NaNO}_3(\text{aq}) + \text{CO}_2(\text{g}) + \text{H}_2\text{O}(\ell)$
- Potassium hydrogen phthalate,  $\text{KHC}_8\text{H}_4\text{O}_4$ , is used to standardize solutions of bases. The acidic anion reacts with strong bases according to the net ionic equation shown below. If a 0.902 g sample of potassium hydrogen phthalate is dissolved in water and titrated to the equivalence point with 26.45 mL of  $\text{NaOH}$ , what is the molar concentration of the  $\text{NaOH}$ ?  
 $\text{HC}_8\text{H}_4\text{O}_4^{-1}(\text{aq}) + \text{OH}^{-1}(\text{aq}) \rightarrow \text{C}_8\text{H}_4\text{O}_4^{-2}(\text{aq}) + \text{H}_2\text{O}(\ell)$
- What quantity of heat is required to raise the temperature of 50.00 mL of water from 25.52 °C to 28.75 °C? The density of water at this temperature is 0.997 g/mL.
- After absorbing 1.850 kJ of heat, the temperature of a 0.500 kg block of copper is 37 °C. What was the initial temperature of the copper?  $C_{\text{Cu}} = 0.385 \text{ J/g}^\circ\text{C}$

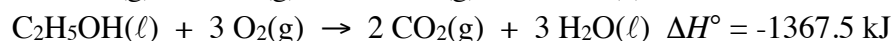
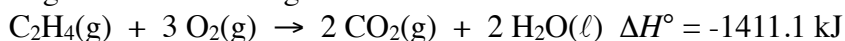
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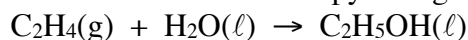
11. A 45.5 g sample of copper at 99.8 °C is dropped into a beaker containing 152 g of water at 18.5 °C. What is the final temperature when thermal equilibrium is reached?  $C_{Cu} = 0.385 \text{ J/g}^\circ\text{C}$
12. A piece of chromium metal with a mass of 24.26 g is heated in boiling water to 98.3 °C and then dropped into a coffee cup calorimeter containing 82.3 g of water at 23.3 °C. When thermal equilibrium is reached, the final temperature is 25.6 °C. Calculate the specific heat of the chromium.
13. Chloromethane,  $\text{CH}_3\text{Cl}$ , arises from the oceans and from microbial fermentation and is found throughout the environment. It is used in the manufacture of various chemicals and has been used as a topical anesthetic. What quantity of heat must be absorbed to convert 92.5 g of liquid to a vapor at its boiling point,  $-24.09^\circ\text{C}$ ? The heat of vaporization of  $\text{CH}_3\text{Cl}$  is 21.40 kJ/mol.
14. Calcium carbide,  $\text{CaC}_2$ , is manufactured by the reaction of  $\text{CaO}$  with carbon at high temperatures. Calcium carbide can then be used to make acetylene. Using the reaction below, is this reaction endothermic or exothermic? If 10.0 g of  $\text{CaO}$  is allowed to react with an excess of carbon, what quantity of heat is absorbed or evolved by the reaction?



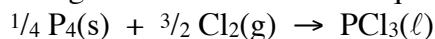
15. The enthalpy changes of the following reactions can be measured:



Use these values and Hess's law to determine the enthalpy change for the reaction:



16. You wish to know the enthalpy change for the formation of liquid  $\text{PCl}_3$  from the elements:



The enthalpy change for the formation of solid  $\text{PCl}_5$  from the elements can be determined experimentally, as can the enthalpy change for the reaction of  $\text{PCl}_3(l)$  with more chlorine to give  $\text{PCl}_5(s)$ . Use the equations below to calculate the enthalpy change for the formation of 1.00 mol  $\text{PCl}_3(l)$  from phosphorus and chlorine.



17. Write a balanced chemical equation for the formation of  $\text{CaCO}_3(s)$  from the elements in their standard states. Find the value of  $\Delta H_f^\circ$  for  $\text{CaCO}_3(s)$  in the table of thermodynamic values. If 10.0 g of  $\text{CaCO}_3(s)$  forms from the elements, how much energy is required or will be released?
18. The first step in the production of nitric acid from ammonia involves the oxidation of  $\text{NH}_3$ :
- $$4 \text{NH}_3(g) + 5 \text{O}_2(g) \rightarrow 4 \text{NO}(g) + 6 \text{H}_2\text{O}(g)$$
- Use standard enthalpies of formation to calculate the standard enthalpy change for this reaction.
  - Using this reaction, what quantity of heat is evolved or absorbed in the *formation* of 10.0 g of  $\text{NH}_3$ ?

## Standard Thermodynamic Properties for Selected Substances

Substance	$\Delta H_f^\circ$ (kJ/mol)	$\Delta G_f^\circ$ (kJ/mol)	$S^\circ$ (J/K·mol)
<b>aluminum</b>			
Al(s)	0	0	28.3
Al(g)	324.4	285.7	164.54
Al <sub>2</sub> O <sub>3</sub> (s)	-1676	-1582	50.92
AlF <sub>3</sub> (s)	-1510.4	-1425	66.5
AlCl <sub>3</sub> (s)	-704.2	-628.8	110.67
AlCl <sub>3</sub> ·6H <sub>2</sub> O(s)	-2691.57	-2269.40	376.56
Al <sub>2</sub> S <sub>3</sub> (s)	-724.0	-492.4	116.9
Al <sub>2</sub> (SO <sub>4</sub> ) <sub>3</sub> (s)	-3445.06	-3506.61	239.32
<b>antimony</b>			
Sb(s)	0	0	45.69
Sb(g)	262.34	222.17	180.16
Sb <sub>4</sub> O <sub>6</sub> (s)	-1440.55	-1268.17	220.92
SbCl <sub>3</sub> (g)	-313.8	-301.2	337.80
SbCl <sub>5</sub> (g)	-394.34	-334.29	401.94
Sb <sub>2</sub> S <sub>3</sub> (s)	-174.89	-173.64	182.00
SbCl <sub>3</sub> (s)	-382.17	-323.72	184.10
SbOCl(s)	-374.0	-	-
<b>arsenic</b>			
As(s)	0	0	35.1
As(g)	302.5	261.0	174.21
As <sub>4</sub> (g)	143.9	92.4	314
As <sub>4</sub> O <sub>6</sub> (s)	-1313.94	-1152.52	214.22
As <sub>2</sub> O <sub>5</sub> (s)	-924.87	-782.41	105.44
AsCl <sub>3</sub> (g)	-261.50	-248.95	327.06
As <sub>2</sub> S <sub>3</sub> (s)	-169.03	-168.62	163.59
AsH <sub>3</sub> (g)	66.44	68.93	222.78
H <sub>3</sub> AsO <sub>4</sub> (s)	-906.3	—	—
<b>barium</b>			
Ba(s)	0	0	62.5
Ba(g)	180	146	170.24
BaO(s)	-548.0	-520.3	72.1
BaCl <sub>2</sub> (s)	-855.0	-806.7	123.7
BaSO <sub>4</sub> (s)	-1473.2	-1362.3	132.2
<b>beryllium</b>			
Be(s)	0	0	9.50
Be(g)	324.3	286.6	136.27
BeO(s)	-609.4	-580.1	13.8
<b>bismuth</b>			
Bi(s)	0	0	56.74
Bi(g)	207.1	168.2	187.00
Bi <sub>2</sub> O <sub>3</sub> (s)	-573.88	-493.7	151.5
BiCl <sub>3</sub> (s)	-379.07	-315.06	176.98
Bi <sub>2</sub> S <sub>3</sub> (s)	-143.1	-140.6	200.4
<b>boron</b>			
B(s)	0	0	5.86
B(g)	565.0	521.0	153.4
B <sub>2</sub> O <sub>3</sub> (s)	-1273.5	-1194.3	53.97
B <sub>2</sub> H <sub>6</sub> (g)	36.4	87.6	232.1
H <sub>3</sub> BO <sub>3</sub> (s)	-1094.33	-968.92	88.83
BF <sub>3</sub> (g)	-1136.0	-1119.4	254.4
BCl <sub>3</sub> (g)	-403.8	-388.7	290.1
B <sub>3</sub> N <sub>3</sub> H <sub>6</sub> (l)	-540.99	-392.79	199.58

## Standard Thermodynamic Properties for Selected Substances

Substance	$\Delta H_f^\circ$ (kJ/mol)	$\Delta G_f^\circ$ (kJ/mol)	$S^\circ$ (J/K·mol)
<b>boron continued</b>			
HBO <sub>2</sub> (s)	-794.25	-723.41	37.66
<b>bromine</b>			
Br <sub>2</sub> (l)	0	0	152.23
Br <sub>2</sub> (g)	30.91	3.142	245.5
Br(g)	111.88	82.429	175.0
BrF <sub>3</sub> (g)	-255.60	-229.45	292.42
HBr(g)	-36.3	-53.43	198.7
<b>cadmium</b>			
Cd(s)	0	0	51.76
Cd(g)	112.01	77.41	167.75
CdO(s)	-258.2	-228.4	54.8
CdCl <sub>2</sub> (s)	-391.5	-343.9	115.3
CdSO <sub>4</sub> (s)	-933.3	-822.7	123.0
CdS(s)	-161.9	-156.5	64.9
<b>calcium</b>			
Ca(s)	0	0	41.6
Ca(g)	178.2	144.3	154.88
CaO(s)	-634.9	-603.3	38.1
Ca(OH) <sub>2</sub> (s)	-985.2	-897.5	83.4
CaSO <sub>4</sub> (s)	-1434.5	-1322.0	106.5
CaSO <sub>4</sub> ·2H <sub>2</sub> O(s)	-2022.63	-1797.45	194.14
CaCO <sub>3</sub> (s) (calcite)	-1220.0	-1081.4	110.0
CaSO <sub>3</sub> ·H <sub>2</sub> O(s)	-1752.68	-1555.19	184.10
<b>carbon</b>			
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 <sub>2</sub> (g)	-393.51	-394.36	213.8
CH <sub>4</sub> (g)	-74.6	-50.5	186.3
CH <sub>3</sub> OH(l)	-239.2	-166.6	126.8
CH <sub>3</sub> OH(g)	-201.0	-162.3	239.9
CCl <sub>4</sub> (l)	-128.2	-62.5	214.4
CCl <sub>4</sub> (g)	-95.7	-58.2	309.7
CHCl <sub>3</sub> (l)	-134.1	-73.7	201.7
CHCl <sub>3</sub> (g)	-103.14	-70.34	295.71
CS <sub>2</sub> (l)	89.70	65.27	151.34
CS <sub>2</sub> (g)	116.9	66.8	238.0
C <sub>2</sub> H <sub>2</sub> (g)	227.4	209.2	200.9
C <sub>2</sub> H <sub>4</sub> (g)	52.4	68.4	219.3
C <sub>2</sub> H <sub>6</sub> (g)	-84.0	-32.0	229.2
CH <sub>3</sub> CO <sub>2</sub> H(l)	-484.3	-389.9	159.8
CH <sub>3</sub> CO <sub>2</sub> H(g)	-434.84	-376.69	282.50
C <sub>2</sub> H <sub>5</sub> OH(l)	-277.6	-174.8	160.7
C <sub>2</sub> H <sub>5</sub> OH(g)	-234.8	-167.9	281.6
C <sub>3</sub> H <sub>8</sub> (g)	-103.8	-23.4	270.3
C <sub>6</sub> H <sub>6</sub> (g)	82.927	129.66	269.2
C <sub>6</sub> H <sub>6</sub> (l)	49.1	124.50	173.4
CH <sub>2</sub> Cl <sub>2</sub> (l)	-124.2	-63.2	177.8
CH <sub>2</sub> Cl <sub>2</sub> (g)	-95.4	-65.90	270.2
CH <sub>3</sub> Cl(g)	-81.9	-60.2	234.6

## Standard Thermodynamic Properties for Selected Substances

Substance	$\Delta H_f^\circ$ (kJ/mol)	$\Delta G_f^\circ$ (kJ/mol)	$S^\circ$ (J/K·mol)
<b>carbon continued</b>			
C <sub>2</sub> H <sub>5</sub> Cl(l)	-136.52	-59.31	190.79
C <sub>2</sub> H <sub>5</sub> Cl(g)	-112.17	-60.39	276.00
C <sub>2</sub> N <sub>2</sub> (g)	308.98	297.36	241.90
HCN(l)	108.9	125.0	112.8
HCN(g)	135.5	124.7	201.8
<b>chlorine</b>			
Cl <sub>2</sub> (g)	0	0	223.1
Cl(g)	121.3	105.70	165.2
ClF(g)	-54.48	-55.94	217.78
ClF <sub>3</sub> (g)	-158.99	-118.83	281.50
Cl <sub>2</sub> O(g)	80.3	97.9	266.2
Cl <sub>2</sub> O <sub>7</sub> (l)	238.1	—	—
Cl <sub>2</sub> O <sub>7</sub> (g)	272.0	—	—
HCl(g)	-92.307	-95.299	186.9
HClO <sub>4</sub> (l)	-40.58	—	—
<b>chromium</b>			
Cr(s)	0	0	23.77
Cr(g)	396.6	351.8	174.50
Cr <sub>2</sub> O <sub>3</sub> (s)	-1139.7	-1058.1	81.2
CrO <sub>3</sub> (s)	-589.5	—	—
(NH <sub>4</sub> ) <sub>2</sub> Cr <sub>2</sub> O <sub>7</sub> (s)	-1806.7	—	—
<b>cobalt</b>			
Co(s)	0	0	30.0
CoO(s)	-237.9	-214.2	52.97
Co <sub>3</sub> O <sub>4</sub> (s)	-910.02	-794.98	114.22
Co(NO <sub>3</sub> ) <sub>2</sub> (s)	-420.5	—	—
<b>copper</b>			
Cu(s)	0	0	33.15
Cu(g)	338.32	298.58	166.38
CuO(s)	-157.3	-129.7	42.63
Cu <sub>2</sub> O(s)	-168.6	-146.0	93.14
CuS(s)	-53.1	-53.6	66.5
Cu <sub>2</sub> S(s)	-79.5	-86.2	120.9
CuSO <sub>4</sub> (s)	-771.36	-662.2	109.2
Cu(NO <sub>3</sub> ) <sub>2</sub> (s)	-302.9	—	—
<b>fluorine</b>			
F <sub>2</sub> (g)	0	0	202.8
F(g)	79.4	62.3	158.8
F <sub>2</sub> O(g)	24.7	41.9	247.43
HF(g)	-273.3	-275.4	173.8
<b>hydrogen</b>			
H <sub>2</sub> (g)	0	0	130.7
H(g)	217.97	203.26	114.7
H <sub>2</sub> O(l)	-285.83	-237.1	70.0
H <sub>2</sub> O(g)	-241.82	-228.59	188.8
H <sub>2</sub> O <sub>2</sub> (l)	-187.78	-120.35	109.6
H <sub>2</sub> O <sub>2</sub> (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	$\Delta H_f^\circ$ (kJ/mol)	$\Delta G_f^\circ$ (kJ/mol)	$S^\circ$ (J/K·mol)
<b>hydrogen continued</b>			
H <sub>2</sub> S(g)	-20.6	-33.4	205.8
H <sub>2</sub> Se(g)	29.7	15.9	219.0
<b>iodine</b>			
I <sub>2</sub> (s)	0	0	116.14
I <sub>2</sub> (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 <sub>7</sub> (g)	-943.91	-818.39	346.44
HI(g)	26.48	1.70	206.59
<b>iron</b>			
Fe(s)	0	0	27.3
Fe(g)	416.3	370.7	180.5
Fe <sub>2</sub> O <sub>3</sub> (s)	-824.2	-742.2	87.40
Fe <sub>3</sub> O <sub>4</sub> (s)	-1118.4	-1015.4	146.4
Fe(CO) <sub>5</sub> (l)	-774.04	-705.42	338.07
Fe(CO) <sub>5</sub> (g)	-733.87	-697.26	445.18
FeCl <sub>2</sub> (s)	-341.79	-302.30	117.95
FeCl <sub>3</sub> (s)	-399.49	-334.00	142.3
FeO(s)	-272.0	-255.2	60.75
Fe(OH) <sub>2</sub> (s)	-569.0	-486.5	88.
Fe(OH) <sub>3</sub> (s)	-823.0	-696.5	106.7
FeS(s)	-100.0	-100.4	60.29
Fe <sub>3</sub> C(s)	25.10	20.08	104.60
<b>lead</b>			
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) <sub>2</sub> (s)	-515.9	—	—
PbS(s)	-100.4	-98.7	91.2
Pb(NO <sub>3</sub> ) <sub>2</sub> (s)	-451.9	—	—
PbO <sub>2</sub> (s)	-277.4	-217.3	68.6
PbCl <sub>2</sub> (s)	-359.4	-314.1	136.0
<b>lithium</b>			
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 <sub>2</sub> CO <sub>3</sub> (s)	-1216.04	-1132.19	90.17
<b>manganese</b>			
Mn(s)	0	0	32.0
Mn(g)	280.7	238.5	173.7
MnO(s)	-385.2	-362.9	59.71
MnO <sub>2</sub> (s)	-520.03	-465.1	53.05
Mn <sub>2</sub> O <sub>3</sub> (s)	-958.97	-881.15	110.46
Mn <sub>3</sub> O <sub>4</sub> (s)	-1378.83	-1283.23	155.64
<b>mercury</b>			
Hg(l)	0	0	75.9

## Standard Thermodynamic Properties for Selected Substances

Substance	$\Delta H_f^\circ$ (kJ/mol)	$\Delta G_f^\circ$ (kJ/mol)	$S^\circ$ (J/K·mol)
<b>mercury continued</b>			
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 <sub>2</sub> (s)	-224.3	-178.6	146.0
Hg <sub>2</sub> Cl <sub>2</sub> (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 <sub>4</sub> (s)	-707.51	-594.13	0.00
<b>nitrogen</b>			
N <sub>2</sub> (g)	0	0	191.6
N(g)	472.704	455.5	153.3
NO(g)	90.25	87.6	210.8
NO <sub>2</sub> (g)	33.2	51.30	240.1
N <sub>2</sub> O(g)	81.6	103.7	220.0
N <sub>2</sub> O <sub>3</sub> (g)	83.72	139.41	312.17
N <sub>2</sub> O <sub>4</sub> (g)	11.1	99.8	304.4
N <sub>2</sub> O <sub>5</sub> (g)	11.3	115.1	355.7
NH <sub>3</sub> (g)	-45.9	-16.5	192.8
N <sub>2</sub> H <sub>4</sub> (l)	50.63	149.43	121.21
N <sub>2</sub> H <sub>4</sub> (g)	95.4	159.4	238.5
NH <sub>4</sub> NO <sub>3</sub> (s)	-365.56	-183.87	151.08
NH <sub>4</sub> Cl(s)	-314.43	-202.87	94.6
NH <sub>4</sub> Br(s)	-270.8	-175.2	113.0
NH <sub>4</sub> I(s)	-201.4	-112.5	117.0
NH <sub>4</sub> NO <sub>2</sub> (s)	-256.5	—	—
HNO <sub>3</sub> (l)	-174.1	-80.7	155.6
HNO <sub>3</sub> (g)	-133.9	-73.5	266.9
<b>oxygen</b>			
O <sub>2</sub> (g)	0	0	205.2
O(g)	249.17	231.7	161.1
O <sub>3</sub> (g)	142.7	163.2	238.9
<b>phosphorus</b>			
P <sub>4</sub> (s)	0	0	164.4
P <sub>4</sub> (g)	58.91	24.4	280.0
P(g)	314.64	278.25	163.19
PH <sub>3</sub> (g)	5.4	13.5	210.2
PCl <sub>3</sub> (g)	-287.0	-267.8	311.78
PCl <sub>5</sub> (g)	-374.9	-305.0	364.4
P <sub>4</sub> O <sub>6</sub> (s)	-1640.1	—	—
P <sub>4</sub> O <sub>10</sub> (s)	-2984.0	-2697.0	228.86
HPO <sub>3</sub> (s)	-948.5	—	—
H <sub>3</sub> PO <sub>2</sub> (s)	-604.6	—	—
H <sub>3</sub> PO <sub>3</sub> (s)	-964.4	—	—
H <sub>3</sub> PO <sub>4</sub> (s)	-1279.0	-1119.1	110.50
H <sub>3</sub> PO <sub>4</sub> (l)	-1266.9	-1124.3	110.5
H <sub>4</sub> P <sub>2</sub> O <sub>7</sub> (s)	-2241.0	—	—
POCl <sub>3</sub> (l)	-597.1	-520.8	222.5
POCl <sub>3</sub> (g)	-558.5	-512.9	325.5
<b>potassium</b>			
K(s)	0	0	64.7
K(g)	89.0	60.5	160.3



## Standard Thermodynamic Properties for Selected Substances

Substance	$\Delta H_f^\circ$ (kJ/mol)	$\Delta G_f^\circ$ (kJ/mol)	$S^\circ$ (J/K·mol)
<b>potassium continued</b>			
KF(s)	-576.27	-537.75	66.57
KCl(s)	-436.5	-408.5	82.6
<b>silicon</b>			
Si(s)	0	0	18.8
Si(g)	450.0	405.5	168.0
SiO <sub>2</sub> (s)	-910.7	-856.3	41.5
SiH <sub>4</sub> (g)	34.3	56.9	204.6
H <sub>2</sub> SiO <sub>3</sub> (s)	-1188.67	-1092.44	133.89
H <sub>4</sub> SiO <sub>4</sub> (s)	-1481.14	-1333.02	192.46
SiF <sub>4</sub> (g)	-1615.0	-1572.8	282.8
SiCl <sub>4</sub> (l)	-687.0	-619.8	239.7
SiCl <sub>4</sub> (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
<b>silver</b>			
Ag(s)	0	0	42.55
Ag(g)	284.9	246.0	172.89
Ag <sub>2</sub> O(s)	-31.05	-11.20	121.3
AgCl(s)	-127.0	-109.8	96.3
Ag <sub>2</sub> S(s)	-32.6	-40.7	144.0
<b>sodium</b>			
Na(s)	0	0	51.3
Na(g)	107.5	77.0	153.7
Na <sub>2</sub> O(s)	-414.2	-375.5	75.1
NaCl(s)	-411.2	-384.1	72.1
<b>sulfur</b>			
S <sub>8</sub> (s) (rhombic)	0	0	256.8
S(g)	278.81	238.25	167.82
SO <sub>2</sub> (g)	-296.83	-300.1	248.2
SO <sub>3</sub> (g)	-395.72	-371.06	256.76
H <sub>2</sub> S(g)	-20.6	-33.4	205.8
H <sub>2</sub> SO <sub>4</sub> (l)	-813.989	690.00	156.90
H <sub>2</sub> S <sub>2</sub> O <sub>7</sub> (s)	-1273.6	—	—
SF <sub>4</sub> (g)	-728.43	-684.84	291.12
SF <sub>6</sub> (g)	-1220.5	-1116.5	291.5
SCl <sub>2</sub> (l)	-50	—	—
SCl <sub>2</sub> (g)	-19.7	—	—
S <sub>2</sub> Cl <sub>2</sub> (l)	-59.4	—	—
S <sub>2</sub> Cl <sub>2</sub> (g)	-19.50	-29.25	319.45
SOCl <sub>2</sub> (g)	-212.55	-198.32	309.66
SOCl <sub>2</sub> (l)	-245.6	—	—
SO <sub>2</sub> Cl <sub>2</sub> (l)	-394.1	—	—
SO <sub>2</sub> Cl <sub>2</sub> (g)	-354.80	-310.45	311.83
<b>tin</b>			
Sn(s)	0	0	51.2
Sn(g)	301.2	266.2	168.5
SnO(s)	-285.8	-256.9	56.5
SnO <sub>2</sub> (s)	-577.6	-515.8	49.0
SnCl <sub>4</sub> (l)	-511.3	-440.1	258.6
SnCl <sub>4</sub> (g)	-471.5	-432.2	365.8

## Standard Thermodynamic Properties for Selected Substances

Substance	$\Delta H_f^\circ$ (kJ/mol)	$\Delta G_f^\circ$ (kJ/mol)	$S^\circ$ (J/K·mol)
<b>titanium</b>			
Ti(s)	0	0	30.7
Ti(g)	473.0	428.4	180.3
TiO <sub>2</sub> (s)	-944.0	-888.8	50.6
TiCl <sub>4</sub> (l)	-804.2	-737.2	252.4
TiCl <sub>4</sub> (g)	-763.2	-726.3	353.2
<b>tungsten</b>			
W(s)	0	0	32.6
W(g)	849.4	807.1	174.0
WO <sub>3</sub> (s)	-842.9	-764.0	75.9
<b>zinc</b>			
Zn(s)	0	0	41.6
Zn(g)	130.73	95.14	160.98
ZnO(s)	-350.5	-320.5	43.7
ZnCl <sub>2</sub> (s)	-415.1	-369.43	111.5
ZnS(s)	-206.0	-201.3	57.7
ZnSO <sub>4</sub> (s)	-982.8	-871.5	110.5
ZnCO <sub>3</sub> (s)	-812.78	-731.57	82.42
<b>complexes</b>			
<i>cis</i> -[Co(NH <sub>3</sub> ) <sub>4</sub> (NO <sub>2</sub> ) <sub>2</sub> ]NO <sub>3</sub>	-898.7	—	—
<i>trans</i> -[Co(NH <sub>3</sub> ) <sub>4</sub> (NO <sub>2</sub> ) <sub>2</sub> ]NO <sub>3</sub>	-896.2	—	—
NH <sub>4</sub> [Co(NH <sub>3</sub> ) <sub>2</sub> (NO <sub>2</sub> ) <sub>4</sub> ]	-837.6	—	—
[Co(NH <sub>3</sub> ) <sub>6</sub> ][Co(NH <sub>3</sub> ) <sub>2</sub> (NO <sub>2</sub> ) <sub>4</sub> ] <sub>3</sub>	-2733.0	—	—
<i>cis</i> -[Co(NH <sub>3</sub> ) <sub>4</sub> Cl <sub>2</sub> ]Cl	-874.9	—	—
<i>trans</i> -[Co(NH <sub>3</sub> ) <sub>4</sub> Cl <sub>2</sub> ]Cl	-877.4	—	—
<i>cis</i> -[Co(en) <sub>2</sub> (NO <sub>2</sub> ) <sub>2</sub> ]NO <sub>3</sub>	-689.5	—	—
<i>cis</i> -[Co(en) <sub>2</sub> Cl <sub>2</sub> ]Cl	-681.2	—	—
<i>trans</i> -[Co(en) <sub>2</sub> Cl <sub>2</sub> ]Cl	-677.4	—	—
[Co(en) <sub>3</sub> ](ClO <sub>4</sub> ) <sub>3</sub>	-762.7	—	—
[Co(en) <sub>3</sub> ]Br <sub>2</sub>	-595.8	—	—
[Co(en) <sub>3</sub> ]I <sub>2</sub>	-475.3	—	—
[Co(en) <sub>3</sub> ]I <sub>3</sub>	-519.2	—	—
[Co(NH <sub>3</sub> ) <sub>6</sub> ](ClO <sub>4</sub> ) <sub>3</sub>	-1034.7	-221.1	615
[Co(NH <sub>3</sub> ) <sub>5</sub> NO <sub>2</sub> ](NO <sub>3</sub> ) <sub>2</sub>	-1088.7	-412.9	331
[Co(NH <sub>3</sub> ) <sub>6</sub> ](NO <sub>3</sub> ) <sub>3</sub>	-1282.0	-524.5	448
[Co(NH <sub>3</sub> ) <sub>5</sub> Cl]Cl <sub>2</sub>	-1017.1	-582.5	366.1
[Pt(NH <sub>3</sub> ) <sub>4</sub> ]Cl <sub>2</sub>	-725.5	—	—
[Ni(NH <sub>3</sub> ) <sub>6</sub> ]Cl <sub>2</sub>	-994.1	—	—
[Ni(NH <sub>3</sub> ) <sub>6</sub> ]Br <sub>2</sub>	-923.8	—	—
[Ni(NH <sub>3</sub> ) <sub>6</sub> ]I <sub>2</sub>	-808.3	—	—

## Standard Thermodynamic Properties for Selected Substances

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