**Periodic Table** (15 points)

1a) (5 points) The ionization energies for the removal of the first electron from atoms of Si, P, S, and Cl are listed in the following table. Briefly rationalize this trend and the exception

| Element | First ionization energy (kJ/mol) |
|---|---|
| Si | 780 |
| P | 1060 |
| S | 1005 |
| Cl | 1235 |

a)

b) (10 points) Suppose a new element, Michigonium, tentatively given the symbol Mi, has just been discovered. Its atomic number is 117.

i) Write the electron configuration of Mi using the noble gas configuration.

ii) Name another element you would expect to find in the same group as Mi.

iii) How many valence electrons would Mi have?

iv) Give the formula for the compound of Mi with Al.

v) Would Mi have a larger or smaller radius than element 116?

**Chemical Bonding and Thermochemistry** (15 points)

*For the following molecules, a) draw the Lewis Structures; b) draw out the shape of the molecule according to VSEPR; c) draw in a "+"ended arrow ( $+\!\!\longrightarrow$ ) to indicate net polarity in the molecule if there is any, d) name the electron pair geometry, and e) name the molecular geometry.*

2a) (10 points) sulfite $SO_3^{-2}$

a) Lewis Structure

b,c) VSEPR

d) electron pair geometry:

e) molecular geometry:

b) (5 points) You are trying to determine the heat capacity of a new metal alloy. A piece of the metal alloy weighing 50 g is heated to 200$^o$C and then placed in a well insulated calorimeter containing 100 g of ice at 0$^o$C. The system is allowed to come to thermal equilibrium and all of the ice has melted into water which is now at 25$^o$C. What is the heat capacity of the metal alloy?

[Heat of fusion of water = 333J/g @ 0$^o$C; Heat capacity of water: 4.184 J/(g $^o$C)]

Hydrofluoric acid (HF) has a $K_a$ =7.2 x$10^{-4}$.

3a) (1 point) What is the expression for $K_a$?

c) (2 points) A 1 M solution of HF is diluted to double its original volume. Does the pH decrease, increase, or stay the same? Why?

Electrochemsitry

4a) (1 point) Lithium batteries, used in small electronics such as watches and pacemakers, are composed of a lithium half cell and a half cell governed by the reaction

$Co^{+3} + e^{-} \rightarrow Co^{+2}$ Write out the ½ reaction for the lithium half cell.

b) (1 point) Is the lithium half reaction an oxidation or reduction reaction?

c (1 point) Would the lithium electrode be the cathode or the anode?

d) (2 points) What is the standard cell potential?

e) (2 points) Lithium has a very negative reduction potential. What other elements would you predict would have similar potentials? Briefly explain why. (Do not choose an element already on the table of standard reduction potentials included in the exam.)

f) (1 point) What is one advantage of lithium over your other choices?

g) (2 points) One reaction on the table of standard reduction potentials has a reduction potential higher than $Co^{+3}$. Why do you think it is not used in batteries?

h) (5 points) If a pacemaker contains a lithium battery made from 0.1M solutions of all ions and is used at body temperature (37$^{o}$C) what is its actual cell potential?

5) (6 points) Given four unknown metals J, Q, X, and Z, and solutions of the nitrate salts of these metals: $J(NO_3)_2$, $Q(NO_3)_2$, $X(NO_3)_2$, $Z(NO_3)_2$. You need to find their relative reduction potentials so you can set up an electrochemical cell. You obtain the following data by placing pieces of metal in the top row into the solutions listed in the leftmost column.

| | J | Q | X | Z |
|---|---|---|---|---|
| $J(NO_3)_2$ | | Precipitation of solid on J | | Precipitation of solid on J |
| $Q(NO_3)_2$ | | | | |
| $X(NO_3)_2$ | Precipitation of solid on X | Precipitation of solid on X | | Precipitation of solid on X |
| $Z(NO_3)_2$ | | Precipitation of solid on N | | |

Blank boxes indicate no observed reaction

a) (1 point) Write out the reduction reaction for each metal:

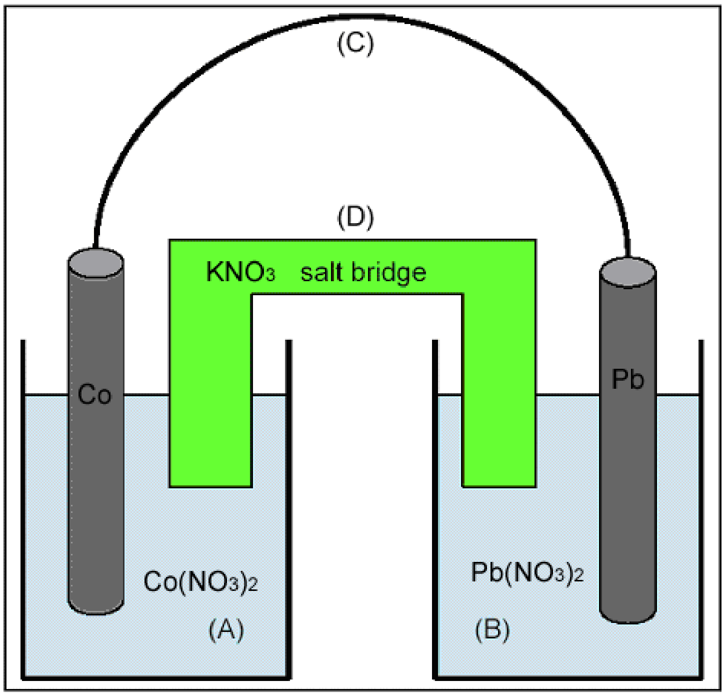
b) (3 points) Rank the metals in order of decreasing reduction potential:

> > >

c) ( 1 point) Which metal would make the best oxidizing agent?

d) (1 point) Which metal would make the best reducing agent?

6) (10 points) An electrochemical cell is constructed as follows: The electrodes are cobalt and lead. Solution (A) contains 1.0 M $Co(NO_3)_2$. Solution (B) contains 1.0 M $Pb(NO_3)_2$ . The salt bridge contains a solution of $KNO_3$. A table of standard reduction potentials is on the next page.




a) (2 points) Write the half-reaction occurring at the cobalt electrode.

Is this the cathode or the anode?

b) (2 points) Write the half-reaction occurring at the lead electrode.

Is this the cathode or the anode?

c) (2 points) Write the balanced net electrochemical reaction and calculate $E^o_{cell}$

d) (2 points) What travels through interconnection (C) and what direction is it flowing?

e) (2 points) What travels through interconnection (D) and describe the direction it is flowing?

Use this abbreviated table of standard reduction potentials to answers the following seven questions.

| | |
|---|---|
| $MnO_4^-{}_{(aq)} + 8H^+{}_{(aq)} + 5e^- \rightarrow Mn^{2+}{}_{(aq)} + 4\ H_2O_{(l)}$ | +1.51 V |
| $Cr_2O_7^{2-}{}_{(aq)} + 6e^- \rightarrow 2\ Cr^{3+}{}_{(aq)} + 7\ H_2O_{(l)}$ | +1.33 V |
| $Pt^{+2}{}_{(aq)} + 2e^- \rightarrow Pt_{(s)}$ | +1.20 V |
| $Cu^{+2}{}_{(aq)} + 2e^- \rightarrow Cu_{(s)}$ | +0.34 V |
| $Pb^{+2}{}_{(aq)} + 2e^- \rightarrow Pb_{(s)}$ | -0.13 V |
| $Al^{+3}{}_{(aq)} + 3e^- \rightarrow Al_{(s)}$ | -1.66 V |

7. How many different cells with $E^o_{cell}$ in excess of +1.90 V can be constructed using the half-reactions given in the table?
a. 1
b. 2
c. 3
d. 4
e. 5

1)

8. The potential for the product-favored reaction involving aluminum and copper metals, $Al^{+3}{}_{(aq)}$, and $Cu^{+2}{}_{(aq)}$ is
a. 2.17 V.
b. 2.00 V.
c. 1.79 V.
d. 1.32 V.
e. 1.15 V.

2)

9. An electrochemical cell is designed using copper as one electrode and another metal higher than copper in the full table of standard reduction potentials (but not in the abbreviated table above) as the other electrode. The cell potential is +0.515 V. The potential for the unknown half-reaction is _____, and that electrode is the _____.
a. 0.175 V; anode
b. 0.175 V; cathode
c. 0.340 V; cathode
d. 0.855 V; anode
e. 0.855 V; cathode

3)

10. The strongest reducing agent in the abbreviated table is
a. $Al_{(s)}$.
b. $Al^{+3}{}_{(aq)}$.
c. $H^+{}_{(aq)}$.
d. $MnO_4^-{}_{(aq)}$..
e. $Mn^{+2}{}_{(aq)}$

4)

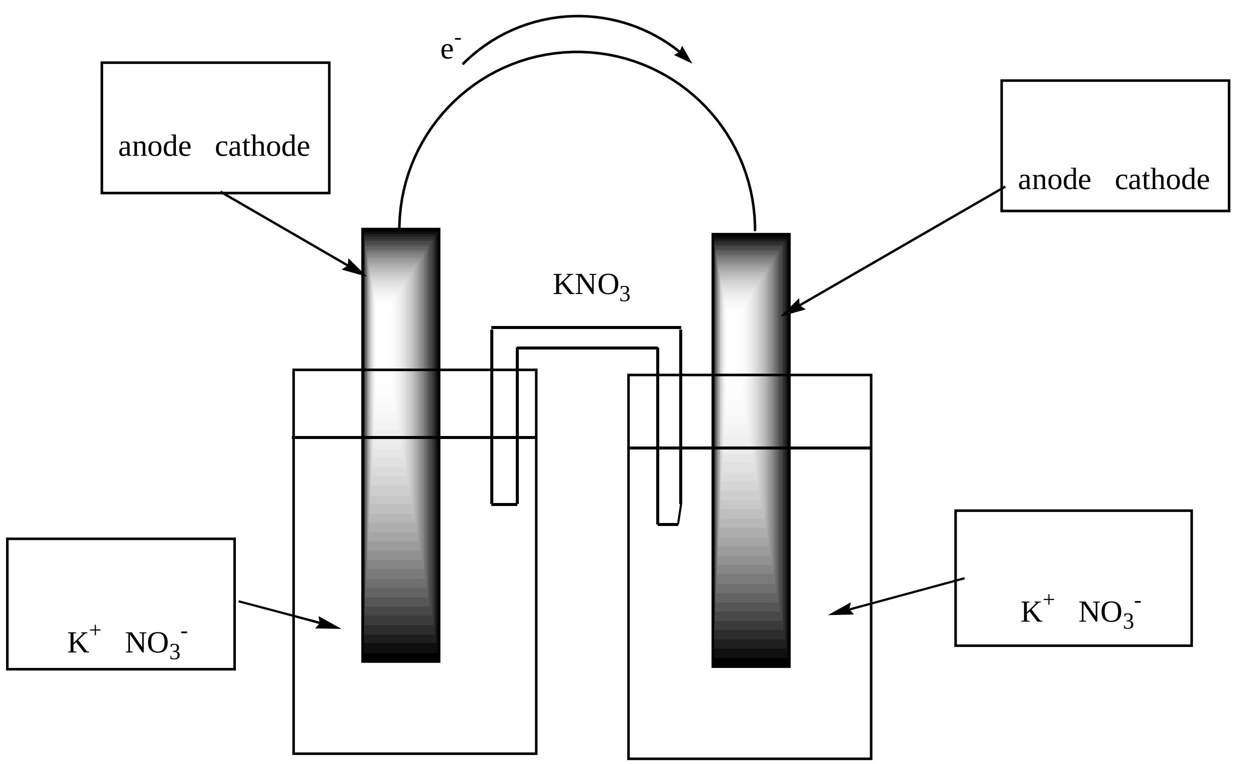
11. Which of these combinations would result in a reaction?
   a. $Al^{+3}_{(aq)}$ and $Cr^{+3}_{(aq)}$.
   b. $Al^{+3}_{(aq)}$ and $Cu_{(s)}$
   c. $Cr_2O_7^{-2}{}_{(aq)}$ and $MnO_4^-{}_{(aq)}$
   d. $Cu_{(s)}$ and $MnO_4^-{}_{(aq)}$.
   e. $Pt_{(s)}$ and $Pb^{+2}_{(aq)}$.

5)

12. The strongest oxidizing agent in the abbreviated table is
   a. $Al_{(s)}$
   b. $Al^{+3}_{(aq)}$
   c. $H^+_{(aq)}$
   d. $MnO_4^-{}_{(aq)}$
   e. $Mn^{+2}_{(aq)}$

6)

14. (*4 points*) The following is a figure of an electrochemical cell. Suppose you were to use copper and lead to make a spontaneous cell. *Fill in the four boxes with Pb, $Pb^{+2}$, Cu, $Cu^{+2}$. In the top two boxes, circle anode or cathode; in the bottom two boxes circle $K^+$ or $NO_3^-$ to indicate which ions from the salt bridge flow into that beaker.*




4

14. (*2 points*) Balance the following redox reaction which takes place under acidic conditions:

$As_2O_3 + NO_3^- \rightarrow H_3AsO_4 + N_2O_3$

2

15. (*5 points*) Identify the following reactions as precipitation, acid/base, or redox: (Circle the appropriate category)

| | |
|---|---|
| $AgNO_{3(aq)} + NaCl_{(aq)} \rightarrow AgCl_{(s)} + NaNO_{3(aq)}$ | precipitation acid/base redox |
| $HIO_3 + FeI_2 + HCl \rightarrow FeCl_3 + ICl + H_2O$ | precipitation acid/base redox |
| $CaF_{(s)} + H_2SO_{4(aq)} \rightarrow HF_{(g)} + CaSO_{4(s)}$ | precipitation acid/base redox |
| $Au(CN)_2^-{}_{(aq)} + Zn_{(s)} \rightarrow Zn^{+2}{}_{(aq)} + Au_{(s)} + CN^-{}_{(aq)}$ | precipitation acid/base redox |
| $2\ HNO_{3(aq)} + Ba(OH)_{2(s)} \rightarrow Ba(NO_3)_{2(aq)} + 2\ H_2O_{(l)}$ | precipitation acid/base redox |

5

16. (*2 points*) Germanium had not been discovered when Mendeleev formulated his ideas of chemical periodicity. He predicted its existence, however, and germanium was discovered in 1886 by Winkler. Write the electron configuration of germanium.

1

For germanium-72 fill in the following information:

| Atomic number | Mass number | # electrons | # neutrons | # protons |
|---|---|---|---|---|
| | | | | |

1

17. (*3 points*) The electron affinities for boron, carbon, nitrogen, and oxygen are listed in the table below.

| Element | Electron Affinity (kJ/mol) |
|---|---|
| B | -27 |
| C | -122 |
| N | >0 |
| O | -141 |

Write out a chemical equation which best describes the electron affinity of boron:

1

Rationalize the trend:

2

18. (*5 points*) Circle the correct word/s in the middle column

| | | |
|---|---|---|
| Carbon has | a smaller a larger the same | electronegativity than/as boron |
| Magnesium has | a smaller a larger the same | radius than/as potassium |
| A mole of copper has | fewer more the same number of | atoms than/as a mole of zinc |
| 200 atoms of sodium have | a smaller a greater the same | mass than/as 100 atoms of tin |
| Arsenic has | fewer more the same number of | electrons in its valence shell as phosphorous |

5

19. (*10 points*) For each of the following three molecules, a) count the number of valence electrons; b) draw the Lewis Structures including all resonance structures and **formal charges**; c) name the electron pair geometry, and d) name the molecular geometry. |

a) $NO_3^-$

# Valence electrons: 1

Lewis Structure:

electron pair geometry:

1

molecular geometry:

3

b) $SOCl_2$

# Valence electrons: 1

Lewis Structure:

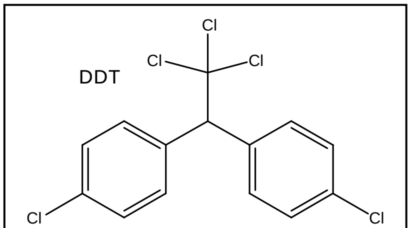
electron pair geometry:

1

molecular geometry:

3

20. (*2 points*) DDT (dichlorodiphenyl trichloroethane) was introduced in the 1950s as one of the first successful insecticides. It brought about increased crop yields and decreased maleria outbreaks. DDT is long-lived and thus accumulates in the fatty tissues of animals (liver, kidney, and skin) and is passes up the food chain. Top predators such as hawks and eagles can accumulate high levels of DDT causing reproduction problems. Thus, DDT has been banned in the US and many other countries. *Based on its chemical structure, rationalize why DDT collects preferentially in the fatty tissues of animals.*




2

30. (*7 points*) 10.05 g of ethanol (ethyl alcohol) is burned according to the equation:

$$CH_3CH_2OH_{(l)} + O_{2(g)} \rightarrow CO_{2(g)} + H_2O_{(g)}$$ (*NOTE: Reaction not balanced*)

How much would the heat given off from burning 10.05g of ethanol raise the temperature of a (12x12x10 ft = $4.08 \times 10^7 cm^3$) room that is initially at $20^oC$?
The heat capacity of air is 1.007 $J/g^oC$ (The density of air is 1.22 g/L; 1 mL = 1 $cm^3$)

| | |
|---|---|
| Increase in room temperature = | 7 |

31. (*4 points*) a) A sample of benzoic acid ($C_6H_5COOH$) is added to water. A small quantity of $D_2O$, water containing the isotope $^2H$ (deuterium = D = $^2H$) is added to the solution. The solution is allowed to stand at constant temperature for several hours, after which the water is evaporated and the remaining solid benzoic acid is found to contain a tiny quantity of deuterium, and the formula of the deuterium-containing molecules is $C_6H_5COOD$. Explain how this can happen.

2

b) In a second experiment with benzoic acid, a tiny quantity of water that contains the isotope $^{18}O$ is added to a solution of benzoic acid in water. When the water is removed and solid benzoic acid is analyzed, no $^{18}O$ is found in the benzoic acid. Compare this situation with the experiment involving deuterium, and explain how the results of the two experiments can differ as they do.

2

**TABLE 19.1** Standard Reduction Potentials in Aqueous Solution at 25 °C*

| Reduction half-reaction | | $E°$ (V) |
|---|---|---|
| $F_2(g) + 2\,e^-$ | $\rightarrow 2\,F^-(aq)$ | +2.87 |
| $H_2O_2(aq) + 2\,H_3O^+(aq) + 2\,e^-$ | $\rightarrow 4\,H_2O(\ell)$ | +1.77 |
| $PbO_2(s) + SO_4^{2-}(aq) + 4\,H_3O^+(aq) + 2\,e^-$ | $\rightarrow PbSO_4(s) + 6\,H_2O(\ell)$ | +1.685 |
| $MnO_4^-(aq) + 8\,H_3O^+(aq) + 5\,e^-$ | $\rightarrow Mn^{2+}(aq) + 12\,H_2O(\ell)$ | +1.52 |
| $Au^{3+}(aq) + 3\,e^-$ | $\rightarrow Au(s)$ | +1.50 |
| $Cl_2(g) + 2\,e^-$ | $\rightarrow 2\,Cl^-(aq)$ | +1.360 |
| $Cr_2O_7^{2-}(aq) + 14\,H_3O^+(aq) + 6\,e^-$ | $\rightarrow 2\,Cr^{3+}(aq) + 21\,H_2O(\ell)$ | +1.33 |
| $O_2(g) + 4\,H_3O^+(aq) + 4\,e^-$ | $\rightarrow 6\,H_2O(\ell)$ | +1.229 |
| $Br_2(\ell) + 2\,e^-$ | $\rightarrow 2\,Br^-(aq)$ | +1.08 |
| $NO_3^-(aq) + 4\,H_3O^+ + 3\,e^-$ | $\rightarrow NO(g) + 6\,H_2O(\ell)$ | +0.96 |
| $OCl^-(aq) + H_2O(\ell) + 2\,e^-$ | $\rightarrow Cl^-(aq) + 2\,OH^-(aq)$ | +0.89 |
| $Hg^{2+}(aq) + 2\,e^-$ | $\rightarrow Hg(\ell)$ | +0.855 |
| $Ag^+(aq) + e^-$ | $\rightarrow Ag(s)$ | +0.80 |
| $Hg_2^{2+}(aq) + 2\,e^-$ | $\rightarrow 2\,Hg(\ell)$ | +0.789 |
| $Fe^{3+}(aq) + e^-$ | $\rightarrow Fe^{2+}(aq)$ | +0.771 |
| $I_2(s) + 2\,e^-$ | $\rightarrow 2\,I^-(aq)$ | +0.535 |
| $O_2(g) + 2\,H_2O(\ell) + 4\,e^-$ | $\rightarrow 4\,OH^-(aq)$ | +0.40 |
| $Cu^{2+}(aq) + 2\,e^-$ | $\rightarrow Cu(s)$ | +0.337 |
| $Sn^{4+}(aq) + 2\,e^-$ | $\rightarrow Sn^{2+}(aq)$ | +0.15 |
| $2\,H_3O^+(aq) + 2\,e^-$ | $\rightarrow H_2(g) + 2\,H_2O(\ell)$ | 0.00 |
| $Sn^{2+}(aq) + 2\,e^-$ | $\rightarrow Sn(s)$ | −0.14 |
| $Ni^{2+}(aq) + 2\,e^-$ | $\rightarrow Ni(s)$ | −0.25 |
| $PbSO_4(s) + 2\,e^-$ | $\rightarrow Pb(s) + SO_4^{2-}(aq)$ | −0.356 |
| $Cd^{2+}(aq) + 2\,e^-$ | $\rightarrow Cd(s)$ | −0.40 |
| $Fe^{2+}(aq) + 2\,e^-$ | $\rightarrow Fe(s)$ | −0.44 |
| $Zn^{2+}(aq) + 2\,e^-$ | $\rightarrow Zn(s)$ | −0.763 |
| $2\,H_2O(\ell) + 2\,e^-$ | $\rightarrow H_2(g) + 2\,OH^-(aq)$ | −0.8277 |
| $Al^{3+}(aq) + 3\,e^-$ | $\rightarrow Al(s)$ | −1.66 |
| $Mg^{2+}(aq) + 2\,e^-$ | $\rightarrow Mg(s)$ | −2.37 |
| $Na^+(aq) + e^-$ | $\rightarrow Na(s)$ | −2.714 |
| $K^+(aq) + e^-$ | $\rightarrow K(s)$ | −2.925 |
| $Li^+(aq) + e^-$ | $\rightarrow Li(s)$ | −3.045 |

* In volts (V) versus the standard hydrogen electrode

**TABLE 6.2** Selected Standard Molar Enthalpies of Formation at 25 °C*

| Formula | Name | Standard Molar Enthalpy of Formation (kJ/mol) | Formula | Name | Standard Molar Enthalpy of Formation (kJ/mol) |
|---|---|---|---|---|---|
| $Al_2O_3(s)$ | Aluminum oxide | −1675.7 | $HI(g)$ | Hydrogen iodide | +26.48 |
| $BaCO_3(s)$ | Barium carbonate | −1216.3 | $KF(s)$ | Potassium fluoride | −567.27 |
| $CaCO_3(s)$ | Calcium carbonate | −1206.92 | $KCl(s)$ | Potassium chloride | −436.747 |
| $CaO(s)$ | Calcium oxide | −635.09 | $KBr(s)$ | Potassium bromide | −393.8 |
| $CCl_4(\ell)$ | Carbon tetrachloride | −135.44 | $MgO(s)$ | Magnesium oxide | −601.70 |
| $CH_4(g)$ | Methane | −74.81 | $MgSO_4(s)$ | Magnesium sulfate | −1284.9 |
| $C_2H_5OH(\ell)$ | Ethyl alcohol | −277.69 | $Mg(OH)_2(s)$ | Magnesium hydroxide | −924.54 |
| $CO(g)$ | Carbon monoxide | −110.525 | $NaF(s)$ | Sodium fluoride | −573.647 |
| $CO_2(g)$ | Carbon dioxide | −393.509 | $NaCl(s)$ | Sodium chloride | −411.153 |
| $C_2H_2(g)$ | Acetylene (ethyne) | +226.73 | $NaBr(s)$ | Sodium bromide | −361.062 |
| $C_2H_4(g)$ | Ethylene (ethene) | +52.26 | $NaI(s)$ | Sodium iodide | −287.78 |
| $C_2H_6(g)$ | Ethane | −84.68 | $NH_3(g)$ | Ammonia | −46.11 |
| $C_3H_8(g)$ | Propane | −103.8 | $NO(g)$ | Nitrogen monoxide | +90.25 |
| $C_4H_{10}(g)$ | Butane | −126.148 | $NO_2(g)$ | Nitrogen dioxide | +33.18 |
| $C_6H_{12}O_6(s)$ | α-D-Glucose | −1274.4 | $PCl_3(\ell)$ | Phosphorus trichloride | −319.7 |
| $CuSO_4(s)$ | Copper(II) sulfate | −771.36 | $PCl_5(s)$ | Phosphorus pentachloride | −443.5 |
| $H_2O(g)$ | Water vapor | −241.818 | $SiO_2(s)$ | Silicon dioxide (quartz) | −910.94 |
| $H_2O(\ell)$ | Liquid water | −285.830 | $SnCl_2(s)$ | Tin(II) chloride | −325.1 |
| $HF(g)$ | Hydrogen fluoride | −271.1 | $SnCl_4(\ell)$ | Tin(IV) chloride | −511.3 |
| $HCl(g)$ | Hydrogen chloride | −92.307 | $SO_2(g)$ | Sulfur dioxide | −296.830 |
| $HBr(g)$ | Hydrogen bromide | −36.40 | $SO_3(g)$ | Sulfur trioxide | −395.72 |