

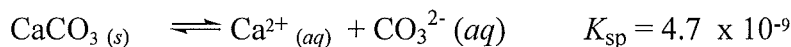
Answer all questions and show work for problems. A formula sheet and periodic table are provided. Please ensure your cell phone is turned off and put away. Please ask if you do not understand a question or think there may be a typo. A gentle reminder that you are to work independently.

1) (2 marks) Which of the following salts, each of which has a solubility product equal to 1.0×10^{-6} , has the greatest molar solubility?

- A. MX $x^2 \quad 10^{-3}$
 B. MX₂ $4x^3 \quad 6.3 \times 10^{-3}$
 C. MX₃ $27x^4 \quad 1.4 \times 10^{-2}$
 D. M₂X $4x^3 \quad 6.3 \times 10^{-3}$
 E. all have the same solubility

C

2) (3 marks) A real world application of solubility products is found in softening "hard water" by removing calcium and magnesium ions present as the sulphate and carbonate salts. We can decrease the amount of Ca²⁺ in solution by addition of sodium carbonate. By increasing the concentration of carbonate, we tend to drive the solubility equilibrium toward the reactant:



If the initial [Ca²⁺] = $5.0 \times 10^{-3} M$, what percent of the [Ca²⁺] will be removed if the carbonate concentration is maintained at $1.0 \times 10^{-3} M$?

$$K_{sp} = [\text{Ca}^{2+}][\text{CO}_3^{2-}]$$

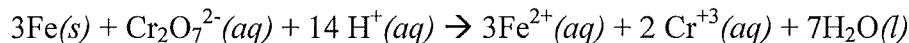
$$4.7 \times 10^{-9} = [\text{Ca}^{2+}][1.0 \times 10^{-3}]$$

$$[\text{Ca}^{2+}] = 4.7 \times 10^{-6}$$

$$\frac{4.7 \times 10^{-6}}{5.0 \times 10^{-3}} \times 100 = 0.094\% \text{ remains}$$

99.91% Ca²⁺ removed

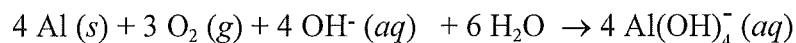
3) (1 mark) For the reaction given below, identify the anode and describe what happens to the electrode as the reaction proceeds.



- A. Pt, no change
 B. Pt, mass decreases
 C. Fe, no change
 D. Fe, mass decreases
 E. Fe, mass increases

D

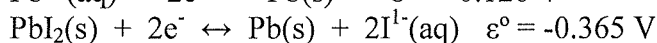
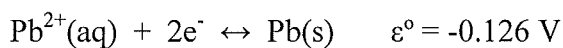
4) (3 marks) Aluminium is used in a battery in which the following reaction occurs:



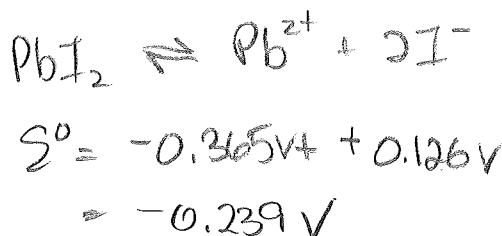
If the battery must supply a current of 78 A for 4.0 hours, what mass of Al (in g) must be contained in the battery?

$$\begin{aligned} ? \text{ g Al} &= 4.0 \text{ hr} \times \frac{3600 \text{ s}}{1 \text{ hr}} \times \frac{78 \text{ C}}{1 \text{ s}} \times \frac{1 \text{ mol e}^-}{96485 \text{ C}} \times \frac{1 \text{ mol Al}}{3 \text{ mol e}^-} \times \frac{26.98 \text{ g Al}}{1 \text{ mol}} \\ &= 105 \text{ g Al} \end{aligned}$$

5) (2 marks) Calculate the K_{sp} of lead iodide at 25°C from the following standard reduction potentials:



- A. 9.1×10^{-5}
- B. 5.0×10^{-9}
- C. 8.3×10^{-9}
- D. 4.5×10^{-13}
- E. 2.5×10^{-17}



C

$$\Delta G^\circ = \frac{0.05916}{2} \log K \quad K = 8.3 \times 10^{-9}$$

6) (2 marks) A refrigerator uses a compressor to do work to “remove the heat” from warm things within it. A foam cup containing 150 g of water at 23.0°C is placed in a refrigerator. What is the minimum work the compressor must do to cool the water to 1.5°C? The specific heat capacity of water is 4.184 J/g °C.

- A. 1.2 kJ
- B. 5.6 kJ
- C. 13 kJ
- D. 18 kJ
- E. 56 kJ

$$\begin{aligned} 150 \text{ g} \times 4.184 \frac{\text{J}}{\text{g}^\circ\text{C}} \times (1.5 - 23.0) \\ = 13.5 \text{ kJ} \end{aligned}$$

C

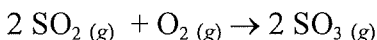
7) (1 mark) Determine the change in energy of a system when an engine does 30 kJ of work while releasing 40 kJ of heat.

- A. -70 kJ
- B. -10 kJ
- C. 10 kJ
- D. 40 kJ
- E. 70 kJ

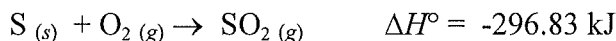
$$\begin{aligned}\Delta E &= q + w \\ &= -40 \text{ kJ} + -30 \text{ kJ} \\ &= -70 \text{ kJ}\end{aligned}$$

A

8) (2 marks) The oxidation of sulphur dioxide to sulphur trioxide is important in the manufacture of sulphuric acid:



Find the enthalpy change of this reaction given the following:



- A. -197.78 kJ
- B. 197.78 kJ
- C. -485.23 kJ
- D. 791.22 kJ
- E. -1088.27 kJ

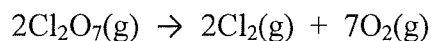
A

9) (3 marks) Mothballs are composed primarily of naphthalene (C_8H_{10} , molar mass 118.18 g). When 1.025 g of naphthalene was combusted in a bomb calorimeter, the temperature was observed to increase from 24.25°C to 32.33°C. The heat capacity of the calorimeter and contents had previously been determined to be 5.11 kJ/°C. Determine the heat of combustion for naphthalene in kJ/mol.

$$\begin{aligned}q_{\text{rxn}} + q_{\text{cal}} &= 0 \\ q_{\text{rxn}} &= -q_{\text{cal}} \\ &= -5.11 \frac{\text{kJ}}{^\circ\text{C}} (32.33^\circ\text{C} - 24.25^\circ\text{C}) \\ &= -41.29 \text{ kJ}\end{aligned}$$

$$-\frac{41.29 \text{ kJ}}{1.025 \text{ g}} \times \frac{118.18 \text{ g}}{1 \text{ mol}} = -4760 \frac{\text{kJ}}{\text{mol}}$$

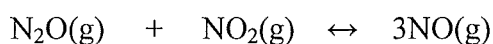
10) (1 mark) Predict ΔS for the following reaction:



- A. negative
- B. positive
- C. close to zero
- D. not enough information to determine
- E. constant

B

11) Consider the following reaction occurring at 298K:



$\Delta H_f^\circ(\text{kJ/mol})$	81.6	33.2	91.3
$S^\circ(\text{J/mol K})$	220.0	240.1	210.8

a) (3 marks) Show that the reaction is not spontaneous under standard conditions.

$$\Delta H_{\text{rxn}}^\circ = 3(91.3 \text{ kJ}) - (81.6 \text{ kJ} + 33.2 \text{ kJ})$$
$$= +159.1 \text{ kJ}$$

$$\Delta S_{\text{rxn}}^\circ = 3(210.8 \frac{\text{J}}{\text{K}}) - (220.0 \frac{\text{J}}{\text{K}} + 240.1 \frac{\text{J}}{\text{K}})$$
$$= -172.3 \frac{\text{J}}{\text{K}}$$

$$\Delta G^\circ = 159.1 \text{ kJ} - 298\text{K} \left(-0.1723 \frac{\text{kJ}}{\text{K}} \right) = +107.7 \text{ kJ}$$

$\Delta G^\circ > 0$ non-spont

b) (2 marks) Can the reaction be made spontaneous by increasing or decreasing the temperature? If so what temperature is required to make the reaction spontaneous under standard conditions?

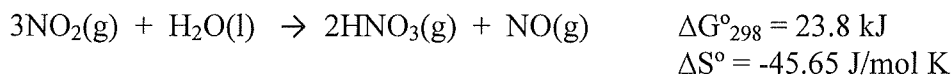
$\Delta G^\circ = 0$ is pt where reaction goes from non-spont to spont

$$\Delta H^\circ = T \Delta S^\circ$$

$$T = \frac{\Delta H^\circ}{\Delta S^\circ} = \frac{159.1 \text{ kJ}}{-0.1723 \text{ kJ/K}} = 923 \text{ K}$$

reaction would be spont under std cond. when
 $T > 923 \text{ K}$

12) Consider the following reaction:



a) (1 mark) Determine ΔG when the pressures of each gas are: $\text{NO}_2 = 2.3 \times 10^{-6} \text{ bar}$, $\text{HNO}_3 = 1.0 \times 10^{-6} \text{ bar}$, $\text{NO} = 1.0 \times 10^{-6} \text{ bar}$. at 25°C .

$$\Delta G = \Delta G^\circ + RT \ln Q$$

$$= -23.8 \text{ kJ} + 8.314 \times 10^{-3} \frac{\text{kJ}}{\text{K}} \times 298 \text{ K} \ln \left(\frac{(1.0 \times 10^{-6})^2 (1.0 \times 10^{-6})}{(2.3 \times 10^{-6})^3} \right)$$

$$= 17.6 \text{ kJ}$$

b) (1 mark) Determine K_p for the reaction at 298 K.

$$\Delta G^\circ = -RT \ln K$$

$$- \frac{23.8 \text{ kJ}}{8.314 \times 10^{-3} \frac{\text{kJ}}{\text{K}} \times 298 \text{ K}} = \ln K \quad K = 6.73 \times 10^{-5}$$

$$\ln K = -9.606$$

c) (3 marks) Determine K_p for the reaction at 398 K.

$$\Delta G^\circ = \Delta H^\circ - T \Delta S^\circ$$

$$\Delta H^\circ = \Delta G^\circ + T \Delta S^\circ$$

$$= 23.8 \text{ kJ} + 298 \text{ K} (-0.04565 \frac{\text{kJ}}{\text{K}})$$

$$= 10.2 \text{ kJ}$$

$$\Delta G^\circ_{398} = 10.2 \text{ kJ} - 398 \text{ K} (-0.04565 \frac{\text{kJ}}{\text{K}})$$

$$= 28.4 \text{ kJ}$$

$$\Delta G^\circ = -RT \ln K$$

$$- \frac{28.4 \text{ kJ}}{8.314 \times 10^{-3} \frac{\text{kJ}}{\text{K}} \times 398 \text{ K}} = \ln K \quad K = 1.89 \times 10^{-4}$$

$$\ln K = -8.57$$

