

Expt. 11: Solubility and Thermodynamics

This lab takes the place of Experiment 11 in your lab manual.

- I. Using either Chrome or Firefox, access the site at <http://chemcollective.org/vlab/87>.

You should see Virtual Lab: Temperature and Solubility of Salts. The window below has a Workbench. On the left-hand side is your Stockroom, where you will get all your equipment and solutions. The right-hand side is your Workbench. You will need to add items from the Stockroom to the Workbench. Keep in mind that the space on your Workbench is not unlimited and that if you refresh the screen, you will lose what is on the Workbench.

Record all your results and answers to the questions on the Data Pages. This will limit the number of pages you have to scan or take photographs of in order to turn in your assignment.

II. The solubility of $\text{Ce}_2(\text{SO}_4)_3$ and $\text{K}_2\text{Cr}_2\text{O}_7$ at two different temperatures

- A. From the Stockroom, acquire the following items on your Workbench:

Distilled water
4 250-mL beakers
Solid $\text{Ce}_2(\text{SO}_4)_3$
Solid $\text{K}_2\text{Cr}_2\text{O}_7$
2 Bunsen burners

- B. Add 100.0 mL of water to each beaker.

- C. For the $\text{Ce}_2(\text{SO}_4)_3$

1. Label one beaker "Room Temperature Ce" and one beaker "High Temperature Ce."
2. Add 50.00 g of $\text{Ce}_2(\text{SO}_4)_3$ to each beaker.
3. While you wait for the Room Temperature beaker to stabilize, place Bunsen burner over the High Temperature beaker and heat the solution until the temperature is somewhere between 60 °C and 80 °C. To stop the heating, use the down arrow on the Bunsen burner and click until it lists 0 kJ/s. This will maintain the heat on your beaker to allow the concentrations to stabilize.
4. Once the concentrations stabilize in both beakers, record the temperatures and concentrations of the Ce^{3+} and SO_4^{2-} ions at each temperature in the Data Table.

D. For the $\text{K}_2\text{Cr}_2\text{O}_7$.

1. Label one beaker "Room Temperature K" and one beaker "High Temperature K."
2. Add 50.00 g of $\text{K}_2\text{Cr}_2\text{O}_7$.
3. While you wait for the Room Temperature beaker to stabilize, place Bunsen burner over the High Temperature beaker and heat the solution until the temperature is somewhere between 60 °C and 80 °C. To stop the heating, use the down arrow on the Bunsen burner and click until it lists 0 kJ/s. This will maintain the heat on your beaker to allow the concentrations to stabilize.
5. Once the concentrations stabilize in both beakers, record the temperatures and concentrations of the K^+ and $\text{Cr}_2\text{O}_7^{2-}$ ions at each temperature in the Data Table.

III. Analyzing the Data

- A. For each salt, write the equilibrium equation for the solubility Data Table and expression for K_{sp} .
- B. Calculate the value of K_{sp} for each temperature and record the values in the Data Table.
- C. Using the equation $\Delta G^\circ = -RT\ln(K)$, calculate the value of ΔG° for each trial. Make sure to use the appropriate temperature in K and the correct value/units for R. Show your calculation and record your values in the Data Table.
- D. For this next part, you will be solving two equations with two unknowns to determine the enthalpy and entropy for each salt. The assumption made is that both entropy and enthalpy are independent of temperature. The process is broken down in steps to help you out. You will follow this process once for each salt.
 1. For $\text{Ce}_2(\text{SO}_4)_3$ and using your numbers for ΔG° and T for the Room Temperature trial, write the equation $\Delta G^\circ = \Delta H^\circ - T\Delta S^\circ$, then rearrange the equation to so that you have ΔH° on the left and all the other numbers/variables on the right. In other words, solve the equation in terms of ΔH° . Show your work in the Data Table.

Example using sample values for ΔG° and T:

$$-24.4 \text{ kJ/mol} = \Delta H^\circ - (298 \text{ K})\Delta S^\circ \text{ rearranged to } \Delta H^\circ = -24.4 \text{ kJ/mol} + (298 \text{ K})\Delta S^\circ$$

2. For $\text{Ce}_2(\text{SO}_4)_3$ and using your numbers for ΔG° and T for the High Temperature, write the equation $\Delta G^\circ = \Delta H^\circ - T\Delta S^\circ$. Then substitute in the equation from part 1 above for ΔH° . This should leave you an equation with just ΔS° as the variable. Solve for ΔS° and show your work in the Data Table.

Example using sample values for ΔG° and T:

$$-28.2 \text{ kJ/mol} = \Delta H^\circ - (358 \text{ K})\Delta S^\circ$$

$$-28.2 \text{ kJ/mol} = -24.4 \text{ kJ/mol} + (298 \text{ K})\Delta S^\circ - (358 \text{ K})\Delta S^\circ$$

$$-3.80 \text{ kJ/mol} = (-60 \text{ K})\Delta S^\circ$$

$$\Delta S^\circ = 0.0633 \text{ kJ/mol}\cdot\text{K}$$

3. Using your value for ΔS° , determine ΔH° .
4. Look at the sign on ΔH° . Does this make sense based on your observation of how the solubility changed with temperature for $\text{Ce}_2(\text{SO}_4)_3$? Why or why not?
5. Look at the sign on ΔS° . Does this make sense based on what you wrote for the equilibrium equation for the solubility of $\text{Ce}_2(\text{SO}_4)_3$? Why or why not?

E. Repeat step D for $\text{K}_2\text{Cr}_2\text{O}_7$ and answer the same questions for this salt.

F. Use the following thermodynamic data to find ΔH° , ΔS° , and ΔG° for the solubility equilibrium of $\text{K}_2\text{Cr}_2\text{O}_7$. These are your theoretical values.

	ΔH° (kJ/mol)	ΔG° (kJ/mol)	ΔS° (J/mol·K)
$\text{K}^+_{(\text{aq})}$	-252.4	-283.3	102.5
$\text{Cr}_2\text{O}_7^{2-}_{(\text{aq})}$	-356.5	-312.8	67.4
$\text{K}_2\text{Cr}_2\text{O}_7_{(\text{s})}$	-1382.8	-1286.0	193.3

Record your values in the Data Table.

G. Calculate the percent error for ΔH° , ΔS° , and ΔG° at Room Temperature that you found in the experiment.

$$\% \text{ error} = \frac{|\text{actual} - \text{theoretical}|}{|\text{theoretical}|} * 100$$

H. Identify a reason as to why your percent error may not be zero.

IV. Submit your Assignment on Thursday 4/30 by 3:30 pm (Section 1003) or 10 pm (Section 2001).

Submit your Data Tables using the "Submit Assignment" button in Canvas for Lab 11.

DATA TABLE PAGE 1:

Ce₂(SO₄)₃:

	Room Temperature	High Temperature
Temperature (°C)	25.00 °C	
[Ce ³⁺] (M)		
[SO ₄ ²⁻] (M)		
Equilibrium equation and expression for K _{sp}		
K _{sp}		
ΔG° (kJ/mol)		
Sample Calculation of ΔG°		
Part D1:		
Part D2:		
ΔS° (J/mol·K)		
ΔH° (kJ/mol)		
Does the sign on ΔH° make sense? Why or why not?		
Does the sign on ΔS° make sense? Why or why not?		

DATA TABLE PAGE 2:

K₂Cr₂O₇:

	Room Temperature	High Temperature	
Temperature (°C)	25.00 °C		
[K ⁺] (M)			
[Cr ₂ O ₇ ²⁻] (M)			
Equilibrium equation and expression for K _{sp}			
K _{sp}			
ΔG° (kJ/mol)			
Sample Calculation of ΔG°			
Part D1:			
Part D2:			
ΔS° (J/mol·K)			
ΔH° (kJ/mol)			
Does the sign on ΔH° make sense? Why or why not?			
Does the sign on ΔS° make sense? Why or why not?			

DATA TABLE PAGE 3:**K₂Cr₂O₇: at Room Temperature**

	Theoretical value	% error
ΔH°		
ΔS°		
ΔG°		
Reason why % error is not zero.		