Problem Set 2
Ch153a – Winter 2026
Due: 23 January 2026

1. (15 points) For each reaction *a-i* given below, calculate the standard Gibbs free energies of formation ($\Delta G_f°$) for all reactants and products, as well as the standard Gibbs free energy change ($\Delta G°$) for the transformation. Standard states are 25 °C, concentrations of 1 molal (1 *m*), partial gas pressures of 100 kPa . The $\Delta G_f°$ values for elements in their pure forms under standard-state conditions are defined to be 0. The table below contains all of the information that you will need to perform these calculations. Express your Gibbs energies in kJ mol^{-1}.

   a. $2H_2CrO_{4(aq)} \rightarrow 2CrO_{2(s)} + O_2 + 2H_2O$
   b. $2H_2MoO_{4(aq)} \rightarrow 2MoO_{2(s)} + O_2 + 2H_2O$
   c. $2H_2WO_{4(s)} \rightarrow 2WO_{2(s)} + O_2 + 2H_2O$
   d. $2MnO_4^-{}_{(aq)} + 2H^+ \rightarrow 2MnO_{2(s)} + \frac{3}{2}O_2 + H_2O$
   e. $2TcO_4^-{}_{(aq)} + 2H^+ \rightarrow 2TcO_{2(s)} + \frac{3}{2}O_2 + H_2O$
   f. $2ReO_4^-{}_{(aq)} + 2H^+ \rightarrow 2ReO_{2(s)} + \frac{3}{2}O_2 + H_2O$
   g. $2FeO_4^{2-}{}_{(aq)} + 4H^+ \rightarrow Fe_2O_{3(s)} + \frac{3}{2}O_2 + 2H_2O$
   h. $RuO_{4(aq)} \rightarrow RuO_{2(s)} + O_2$
   i. $OsO_{4(aq)} \rightarrow OsO_{2(s)} + O_2$

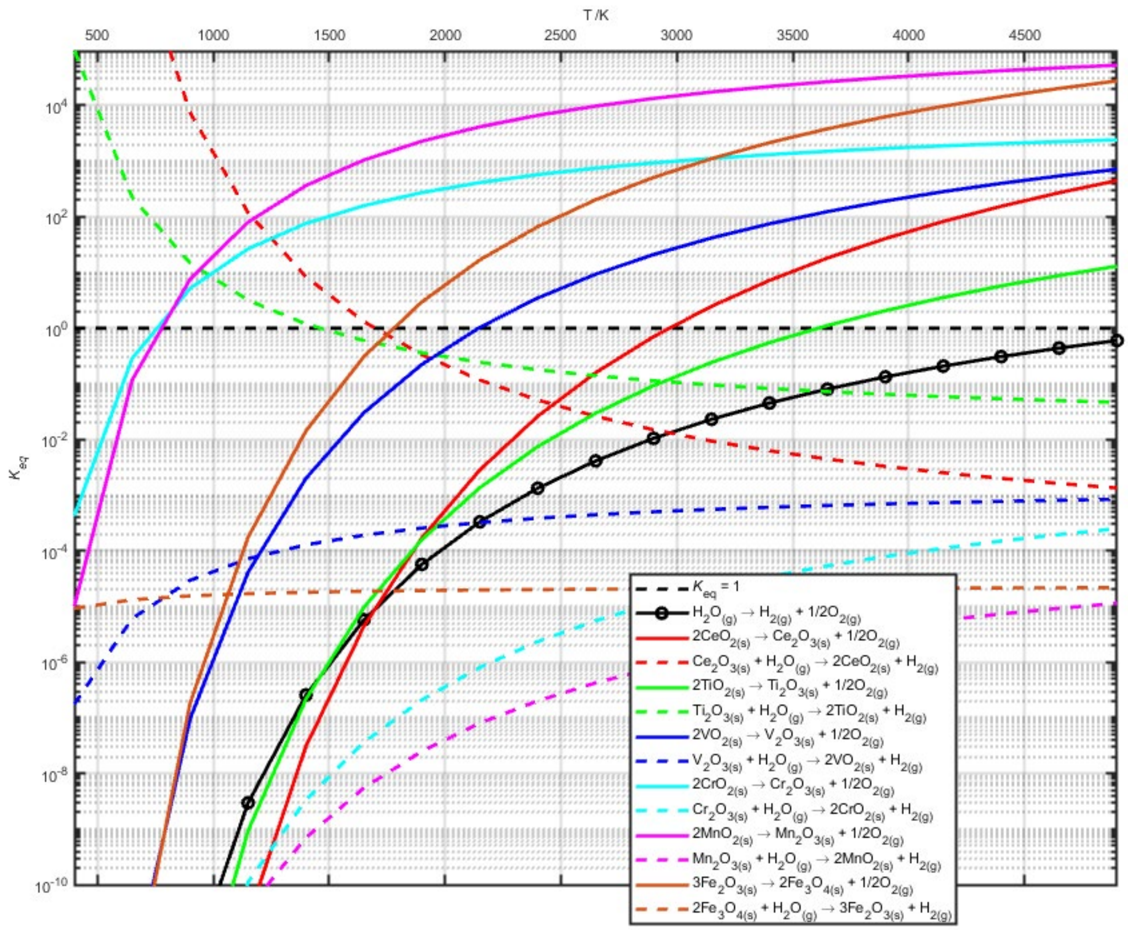
Species	**Conditions**	**$\Delta G_f°$ kJ mol^{-1}**
H^+	1 m, aqueous solution	0
HO^-	1 m, aqueous solution	−157.3
H_2O	liquid	−237.2

Half-reaction	**$E°$, V vs. NHE**
$O_2 + 4H^+ + 4e^- \rightarrow 2H_2O$	1.229
$H_2CrO_{4(aq)} + 6H^+ + 6e^- \rightarrow Cr_{(s)} + 4H_2O$	0.325
$CrO_{2(s)} + 4H^+ + 4e^- \rightarrow Cr_{(s)} + 2H_2O$	–0.191
$H_2MoO_{4(aq)} + 6H^+ + 6e^- \rightarrow Mo_{(s)} + 4H_2O$	0.114
$MoO_{2(s)} + 4H^+ + 4e^- \rightarrow Mo_{(s)} + 2H_2O$	–0.152
$H_2WO_{4(s)} + 6H^+ + 6e^- \rightarrow W_{(s)} + 4H_2O$	–0.089
$WO_{2(s)} + 4H^+ + 4e^- \rightarrow W_{(s)} + 2H_2O$	–0.154
$MnO_4^-{}_{(aq)} + 8H^+ + 7e^- \rightarrow Mn_{(s)} + 4H_2O$	0.698
$MnO_{2(s)} + 4H^+ + 4e^- \rightarrow Mn_{(s)} + 2H_2O$	0.024
$TcO_4^-{}_{(aq)} + 8H^+ + 7e^- \rightarrow Tc_{(s)} + 4H_2O$	0.472
$TcO_{2(s)} + 4H^+ + 4e^- \rightarrow Tc_{(s)} + 2H_2O$	0.272
$ReO_4^-{}_{(aq)} + 8H^+ + 7e^- \rightarrow Re_{(s)} + 4H_2O$	0.376
$ReO_{2(s)} + 4H^+ + 4e^- \rightarrow Re_{(s)} + 2H_2O$	0.216

$FeO_4^{2-}{}_{(aq)} + 8H^+ + 6e^- \rightarrow Fe_{(s)} + 4H_2O$	1.505
$Fe_2O_{3(s)} + 6H^+ + 6e^- \rightarrow 2Fe_{(s)} + 3H_2O$	–0.055
$RuO_{4(aq)} + 8H^+ + 8e^- \rightarrow Ru_{(s)} + 4H_2O$	1.039
$RuO_{2(s)} + 4H^+ + 4e^- \rightarrow Ru_{(s)} + 2H_2O$	0.673
$OsO_{4(aq)} + 8H^+ + 8e^- \rightarrow Os_{(s)} + 4H_2O$	0.838
$OsO_{2(s)} + 4H^+ + 4e^- \rightarrow Os_{(s)} + 2H_2O$	0.687

2. (5 points) On the basis of your ΔG° values for the reactions from problem 1, which of the metal dioxides would be likely candidates for water oxidation catalysts? Would the one sesquioxide be a candidate? Explain your reasoning.

3. (10 points) Consider the H_2 and O_2 evolution reactions of several metal oxides depicted in the plot on the following page.
   a) Identify which reactions are endothermic and which are exothermic.
   b) Identify the algebraic sign of the entropy change for each reaction.
   c) Which reaction has the smallest value of $|\Delta H^\circ|$?
   d) Which metal oxide pair(s) might be used in a thermal water-splitting cycle? Explain your reasoning.



T / K
500
1000
1500
2000
2500
3000
3500
4000
4500
K_{eq}
10^{4}
10^{2}
10^{0}
10^{-2}
10^{-4}
10^{-6}
10^{-8}
10^{-10}
$K_{eq} = 1$
$H_2O_{(g)} \rightarrow H_{2(g)} + 1/2O_{2(g)}$
$2CeO_{2(s)} \rightarrow Ce_2O_{3(s)} + 1/2O_{2(g)}$
$Ce_2O_{3(s)} + H_2O_{(g)} \rightarrow 2CeO_{2(s)} + H_{2(g)}$
$2TiO_{2(s)} \rightarrow Ti_2O_{3(s)} + 1/2O_{2(g)}$
$Ti_2O_{3(s)} + H_2O_{(g)} \rightarrow 2TiO_{2(s)} + H_{2(g)}$
$2VO_{2(s)} \rightarrow V_2O_{3(s)} + 1/2O_{2(g)}$
$V_2O_{3(s)} + H_2O_{(g)} \rightarrow 2VO_{2(s)} + H_{2(g)}$
$2CrO_{2(s)} \rightarrow Cr_2O_{3(s)} + 1/2O_{2(g)}$
$Cr_2O_{3(s)} + H_2O_{(g)} \rightarrow 2CrO_{2(s)} + H_{2(g)}$
$2MnO_{2(s)} \rightarrow Mn_2O_{3(s)} + 1/2O_{2(g)}$
$Mn_2O_{3(s)} + H_2O_{(g)} \rightarrow 2MnO_{2(s)} + H_{2(g)}$
$3Fe_2O_{3(s)} \rightarrow 2Fe_3O_{4(s)} + 1/2O_{2(g)}$
$2Fe_3O_{4(s)} + H_2O_{(g)} \rightarrow 3Fe_2O_{3(s)} + H_{2(g)}$