Before you begin, make sure that your exam has all 7 pages. There are 14 required problems (7 points each) and two extra credit problems (5 points each). Stay focused, stay calm. Work steadily through your exam.

YOU MUST:
Put your name and student ID on the bubble sheet correctly.
Put all your answers on the bubble sheet; nothing on this exam will be used for grading.
Sign the statement on the last page of the exam.
Turn in both the exam and bubble sheet when you are done. Good Luck!

Physical Constants:

\[ R = 0.008314 \text{ kJ/(K mol)} \quad F = 96.485 \text{ kJ/(mol eV)} \quad \mathcal{N}^\circ = 6.02 \times 10^{23} \]

\[ F = 96,485 \text{ C/(mol e)} \]

Useful Equations:

\[ \Delta S = q_{\text{rev}}/T \quad q_{\text{rev}} = \Delta H_{\text{sys}} \quad \Delta S_{\text{sys}} = \Sigma S(\text{products}) - \Sigma S(\text{reactants}) \quad \Delta S_{\text{univ}} = \Delta S_{\text{surr}} + \Delta S_{\text{sys}} \]

\[ \Delta G_{\text{sys}} = \Delta H_{\text{sys}} - T\Delta S_{\text{sys}} \quad \Delta G^{\circ}_{\text{rxn}} = \Sigma \Delta G^{\circ}_{f}(\text{products}) - \Sigma \Delta G^{\circ}_{f}(\text{reactants}) \]

\[ \Delta G = \Delta G^{\circ} + (RT)\ln Q \quad \Delta G^{\circ} = -(RT)\ln K \quad w_{\text{max}} = -\Delta G_{\text{sys}} \]
Useful Equations (cont’d):

\[ E_{\text{cell}}^{\circ} = E_{\text{cathode}}^{\circ} - E_{\text{anode}}^{\circ} \]  
(1/2 reactions are expressed as reductions)

At \( T = 298.15 \, \text{K} \),  
\[ E_{\text{cell}}^{\circ} = E_{\text{reduction} \frac{1}{2} \text{rxn}}^{\circ} + E_{\text{oxidation} \frac{1}{2} \text{rxn}}^{\circ} \]

\[ E = E_{\text{cell}}^{\circ} - (RT/nF)\ln Q \]

\[ w_{\text{max}} = nFE \]

\[ \Delta G = -nFE \]

\[ E_{\text{reduction}}^{\circ} = \frac{RT}{nF} \ln K \]

Current (amperes, A) = \([\text{electric charge (coulombs, C)}/[\text{time (seconds, s)}])\]

Electric charge (coulombs, C) = \([n (\text{moles of electrons transferred}) \times [F (\text{coulombs/mole e}^-)]\]

**TABLES of DATA – All the Necessary Data are Presented with the Problem**
1. Which of the following linear alkane molecules is likely to have the largest standard entropy?
   A. CH₄
   B. CH₂CH₃
   C. CH₃CH₂CH₃
   D. CH₂CH₂CH₂CH₃
   E. CH₃CH₂CH₂CH₂CH₃

2. All of the following statements concerning entropy are true EXCEPT
   A. entropy values for substances are greater than or equal to zero.
   B. entropy is a thermodynamic state function.
   C. entropy is zero for elements under standard conditions.
   D. a positive change in entropy denotes a change toward greater disorder.

3. Which reaction is likely to have a negative change in entropy?
   A. 2 NH₃(g) → N₂(g) + 3 H₂(g)
   B. CaCO₃(s) → CaO(s) + CO₂(g)
   C. N₂O₄(g) → 2 NO₂(g)
   D. 2 CO(g) → 2 C(s) + O₂(g)

4. The dissolution of ammonium nitrate (NH₄NO₃) occurs spontaneously in water at 25 °C. As it dissolves, the temperature of the water decreases. What are the signs of ΔH, ΔS, and ΔG for this process?
   A. ΔH > 0, ΔS < 0, ΔG > 0
   B. ΔH > 0, ΔS > 0, ΔG < 0
   C. ΔH > 0, ΔS > 0, ΔG > 0
   D. ΔH < 0, ΔS < 0, ΔG < 0
5. What is the correct equilibrium constant expression for the balanced reaction shown below?

\[ \text{C}_3\text{H}_8(\text{g}) + 5\text{O}_2(\text{g}) \rightleftharpoons 3\text{CO}_2(\text{g}) + 4\text{H}_2\text{O}(\text{l}) \]

\[ K = \frac{[\text{CO}_2]^3[\text{H}_2\text{O}]^4}{[\text{C}_3\text{H}_8][\text{O}_2]^5} \]

A. \[ K = \frac{[\text{CO}_2][\text{H}_2\text{O}]}{[\text{C}_3\text{H}_8][\text{O}_2]} \]

B. \[ K = \frac{[\text{CO}_2]}{[\text{C}_3\text{H}_8][\text{O}_2]} \]

C. \[ K = \frac{[\text{CO}_2]^3}{[\text{C}_3\text{H}_8][\text{O}_2]^5} \]

D. \[ K = \frac{[\text{CO}_2][\text{H}_2\text{O}]}{[\text{C}_3\text{H}_8][\text{O}_2]^5} \]

6. At what temperatures will a reaction be spontaneous if \( \Delta H = +158 \text{ kJ} \) and \( \Delta S = +411 \text{ J/K} \)?

A. All temperatures below 384 K
B. All temperatures above 384 K
C. Temperatures between 158 K and 411 K
D. The reaction will be spontaneous at any temperature.
E. The reaction will never be spontaneous.

7. Calculate \( \Delta G^\circ \) for the following reaction at 425 °C, at which temperature \( K_{eq} = 56 \).

\[ \text{H}_2(\text{g}) + \text{I}_2(\text{g}) \rightleftharpoons 2\text{HI}(\text{g}) \quad (R = 8.314 \text{ J/K\cdotmol}) \]

A. -23.4 kJ  B. -14.2 kJ  C. -10.1 kJ  D. -6.18 kJ  E. +14.2 kJ
8. In the reduction of HClO₄ to Cl⁻ (HClO₄ \rightarrow \text{Cl}⁻), the oxidation state of Cl changes by

A. -7  
B. +7  
C. -8  
D. +8

9. Write a balanced half-reaction for the reduction of ClO₃⁻(aq) to Cl₂(g) in an acidic solution.

A. \(2 \text{ ClO}_3^-(aq) + 6 \text{ H}^+(aq) + 10 e^- \rightarrow \text{Cl}_2(g) + 6 \text{ OH}^-(aq)\)  
B. \(2 \text{ ClO}_3^-(aq) + 12 \text{ H}^+(aq) + 5 e^- \rightarrow \text{Cl}_2(g) + 6 \text{ H}_2\text{O}(l)\)  
C. \(2 \text{ ClO}_3^-(aq) + 10 e^- \rightarrow \text{Cl}_2(g) + 6 \text{ H}_2\text{O}(l) + 3 \text{ O}_2(g)\)  
D. \(2 \text{ ClO}_3^-(aq) + 12 \text{ H}^+(aq) + 10 e^- \rightarrow \text{Cl}_2(g) + 6 \text{ H}_2\text{O}(l)\)  
E. none of these are balanced

10. Use the standard reduction potentials below to determine which element or ion is the best reducing agent.

\[
\begin{align*}
\text{Pd}^{2+}(aq) + 2 e^- & \rightarrow \text{Pd}(s) & E^o &= +0.90 \text{ V} \\
\text{Sn}^{2+}(aq) + 2 e^- & \rightarrow \text{Sn}(s) & E^o &= -0.14 \text{ V} \\
\text{Cr}^{2+}(aq) + 2 e^- & \rightarrow \text{Cr}(s) & E^o &= -0.91 \text{ V} \\
\end{align*}
\]

A. Pd²⁺  
B. Cr(s)  
C. Sn²⁺  
D. Cr²⁺  
E. Pd(s)

11. Which of the following statements about the reaction is correct?  
\((\text{Cr}^{3+} + 3e^- \rightarrow \text{Cr}, E^o = -0.74 \text{ V}) (\text{Cd}^{2+} + 2e^- \rightarrow \text{Cd}, E^o = -0.403 \text{ V})\)

\[3\text{Cd}^{2+}(aq) + 2\text{Cr}(s) \rightarrow 3\text{Cd}(s) + 2\text{Cr}^{3+}(aq)\]

A. \(E^o_{\text{cell}} < 0\)  
B. \(\Delta G^o < 0\)  
C. 6 moles of electrons are transferred in the reaction  
D. A and C  
E. B and C
12. In an electrochemical cell . . .

A. the oxidation process occurs at the anode.
B. the reduction process occurs at the cathode.
C. the salt bridge enables electrical connection through the cell by making a physical connection between the anode and cathode compartments.
D. All of the above.
E. Just A and B.

13. Given the following two half-reactions, determine which of the overall reactions is spontaneous and calculate its standard cell potential.

\[ \text{Al}^{3+}(aq) + 3 \text{e}^- \rightarrow \text{Al}(s) \quad E^\circ = -1.66 \text{ V} \]
\[ \text{Cu}^{2+}(aq) + 2 \text{e}^- \rightarrow \text{Cu}(s) \quad E^\circ = +0.34 \text{ V} \]

A. \[ 2 \text{ Al}^{3+}(aq) + 3 \text{ Cu}(s) \rightarrow 2 \text{ Al}(s) + 3 \text{ Cu}^{2+}(aq) \quad E^\circ_{\text{cell}} = -2.00 \text{ V} \]
B. \[ 2 \text{ Al}^{3+}(aq) + 3 \text{ Cu}(s) \rightarrow 2 \text{ Al}(s) + 3 \text{ Cu}^{2+}(aq) \quad E^\circ_{\text{cell}} = +2.00 \text{ V} \]
C. \[ 2 \text{ Al}(s) + 3 \text{ Cu}^{2+}(aq) \rightarrow 2 \text{ Al}^{3+}(aq) + 3 \text{ Cu}(s) \quad E^\circ_{\text{cell}} = +2.00 \text{ V} \]
D. \[ 2 \text{ Al}(s) + 3 \text{ Cu}^{2+}(aq) \rightarrow 2 \text{ Al}^{3+}(aq) + 3 \text{ Cu}(s) \quad E^\circ_{\text{cell}} = -1.32 \text{ V} \]

14. Calculate \( E \) for the following electrochemical cell reaction at 298 K

\[ \text{Sn}^{2+}(aq) + 2\text{AgI}(s) \rightarrow \text{Sn}^{4+}(aq) + 2\text{I}^- (aq) + \text{Ag}(s) \]

where

\[ [\text{Sn}^{2+}] = 0.50 \text{ M} \quad [\text{Sn}^{4+}] = 0.50 \text{ M} \quad [\text{I}^-] = 0.15 \text{ M} \]
\[ \text{AgI}(s) + \text{e}^- \rightarrow \text{Ag}(s) + \text{I}^- (aq) \quad E^\circ = -0.15 \text{ V} \]
\[ \text{Sn}^{4+}(aq) + 2 \text{e}^- \rightarrow \text{Sn}^{2+}(aq) \quad E^\circ = +0.15 \text{ V} \]

A. +0.05 V   B. -0.25 V   C. -0.30 V   D. -0.32 V   E. -0.35 V
EXTRA CREDIT (5 points each)

15. Citric Acid (Cit) binds reversibly to Citric Acid binding protein (CBP) with an equilibrium constant of $2.96 \times 10^6$. The enthalpy of binding is $-102.4 \text{ kJ mol}^{-1}$.

$$\text{CBP} + \text{Cit} \rightleftharpoons \text{CBP:Cit}$$

What is the entropy of binding at 25 °C?

A. $-36.9 \text{ J/K}$  
B. $-220 \text{ J/K}$  
C. $-346 \text{ J/K}$  
D. $-3970 \text{ J/K}$

16. To generate 1 kilogram (1000 grams) of Al from Al$_2$O$_3$ in an electrolytic cell in 1 hour, what is the electrical current (in amperes) that must be supplied to the cell?

A. $1.07 \times 10^7$  
B. $3.58 \times 10^6$  
C. 2980  
D. 990

Please sign the following statement at the completion of the exam.

I, ________________________________________________ (print name) pledge not to discuss this test with anyone who has not it the tests until are graded and returned.

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