

The key for the exam will be posted shortly afterwards at noblereaction.org/gc/202misc.htm. If you record your answers, you will be able to grade your exam.

Appendix C

HALF-CELL POTENTIALS

	$E_{1/2}^\circ$ in V
1. $\text{O}_3(g) + 2 \text{H}^+(aq) + 2 e^- \rightleftharpoons \text{O}_2(g) + \text{H}_2\text{O}(l)$	2.08
2. $\text{Co}^{3+}(aq) + e^- \rightleftharpoons \text{Co}^{2+}(aq)$	1.92
3. $\text{Au}^+(aq) + e^- \rightleftharpoons \text{Au}(s)$	1.69
4. $\text{MnO}_4^-(aq) + 8 \text{H}^+(aq) + 5 e^- \rightleftharpoons \text{Mn}^{2+}(aq) + 4 \text{H}_2\text{O}(l)$	1.51
5. $\text{HClO}(aq) + \text{H}^+(aq) + 2 e^- \rightleftharpoons \text{Cl}^-(aq) + \text{H}_2\text{O}(l)$	1.48
6. $\text{ClO}_3^-(aq) + 6 \text{H}^+(aq) + 6 e^- \rightleftharpoons \text{Cl}^-(aq) + 3 \text{H}_2\text{O}(l)$	1.45
7. $\text{Au}^{3+}(aq) + 2 e^- \rightleftharpoons \text{Au}^+(aq)$	1.40
8. $\text{Cl}_2(g) + 2 e^- \rightleftharpoons 2 \text{Cl}^-(aq)$	1.36
9. $\text{HCrO}_4^-(aq) + 7 \text{H}^+(aq) + 3 e^- \rightleftharpoons \text{Cr}^{3+}(aq) + 4 \text{H}_2\text{O}(l)$	1.35
10. $2 \text{HNO}_2(aq) + 4 \text{H}^+(aq) + 4 e^- \rightleftharpoons \text{N}_2\text{O}(g) + 3 \text{H}_2\text{O}(l)$	1.30
11. $\text{O}_2(g) + 4 \text{H}^+(aq) + 4 e^- \rightleftharpoons 2 \text{H}_2\text{O}(l)$	1.23
12. $\text{MnO}_2(s) + 4 \text{H}^+(aq) + 2 e^- \rightleftharpoons \text{Mn}^{2+}(aq) + 2 \text{H}_2\text{O}(l)$	1.22
13. $\text{SeO}_4^{2-}(aq) + 4 \text{H}^+(aq) + 2 e^- \rightleftharpoons \text{H}_2\text{SeO}_3(aq) + \text{H}_2\text{O}(l)$	1.15
14. $\text{IO}_3^-(aq) + 6 \text{H}^+(aq) + 6 e^- \rightleftharpoons \text{I}^-(aq) + 3 \text{H}_2\text{O}(l)$	1.08
15. $\text{Br}_2(l) + 2 e^- \rightleftharpoons 2 \text{Br}^-(aq)$	1.07
16. $\text{NO}_3^-(aq) + 4 \text{H}^+(aq) + 3 e^- \rightleftharpoons \text{NO}(g) + 2 \text{H}_2\text{O}(l)$	0.96
17. $\text{Ag}^+(aq) + e^- \rightleftharpoons \text{Ag}(s)$	0.80
18. $\text{Fe}^{3+}(aq) + e^- \rightleftharpoons \text{Fe}^{2+}(aq)$	0.77
19. $\text{O}_2(g) + 2 \text{H}^+(aq) + 2 e^- \rightleftharpoons \text{H}_2\text{O}_2(aq)$	0.70
20. $\text{ClO}_3^-(aq) + 3 \text{H}_2\text{O}(l) + 6 e^- \rightleftharpoons \text{Cl}^-(aq) + 6 \text{OH}^-(aq)$	0.62
21. $\text{MnO}_4^-(aq) + 2 \text{H}_2\text{O}(l) + 3 e^- \rightleftharpoons \text{MnO}_2(s) + 4 \text{OH}^-(aq)$	0.60
22. $\text{I}_2(s) + 2 e^- \rightleftharpoons 2 \text{I}^-(aq)$	0.54
23. $\text{Cu}^+(aq) + e^- \rightleftharpoons \text{Cu}(s)$	0.52
24. $\text{O}_2(g) + 2 \text{H}_2\text{O}(l) + 4 e^- \rightleftharpoons 4 \text{OH}^-(aq)$	0.40
25. $\text{Cu}^{2+}(aq) + 2 e^- \rightleftharpoons \text{Cu}(s)$	0.34
26. $\text{ClO}_3^-(aq) + \text{H}_2\text{O}(l) + 2 e^- \rightleftharpoons \text{ClO}_2^-(aq) + 2 \text{OH}^-(aq)$	0.33
27. $\text{AgCl}(s) + e^- \rightleftharpoons \text{Ag}(s) + \text{Cl}^-(aq)$	0.22
28. $\text{Cu}^{2+}(aq) + e^- \rightleftharpoons \text{Cu}^+(aq)$	0.15
29. $\text{Sn}^{4+}(aq) + 2 e^- \rightleftharpoons \text{Sn}^{2+}(aq)$	0.15
30. $2 \text{H}^+(aq) + 2 e^- \rightleftharpoons \text{H}_2(g)$	0.00
31. $\text{Fe}^{3+}(aq) + 3 e^- \rightleftharpoons \text{Fe}(s)$	-0.04
32. $\text{SnO}_2(s) + 4 \text{H}^+(aq) + 2 e^- \rightleftharpoons \text{Sn}^{2+}(aq) + 2 \text{H}_2\text{O}(l)$	-0.09
33. $\text{Sn}^{2+}(aq) + 2 e^- \rightleftharpoons \text{Sn}(s)$	-0.14
34. $\text{Ni}^{2+}(aq) + 2 e^- \rightleftharpoons \text{Ni}(s)$	-0.26
35. $\text{Cr}^{3+}(aq) + e^- \rightleftharpoons \text{Cr}^{2+}(aq)$	-0.41
36. $\text{Fe}^{2+}(aq) + 2 e^- \rightleftharpoons \text{Fe}(s)$	-0.45
37. $\text{NO}_2^-(aq) + \text{H}_2\text{O}(l) + e^- \rightleftharpoons \text{NO}(g) + 2 \text{OH}^-(aq)$	-0.46
38. $\text{H}_3\text{PO}_3(aq) + 2 \text{H}^+(aq) + 2 e^- \rightleftharpoons \text{H}_3\text{PO}_2(aq) + \text{H}_2\text{O}(l)$	-0.50
39. $2 \text{SO}_3^{2-}(aq) + 3 \text{H}_2\text{O}(l) + 4 e^- \rightleftharpoons \text{S}_2\text{O}_3^{2-}(aq) + 6 \text{OH}^-(aq)$	-0.57
40. $\text{Cr}^{3+}(aq) + 3 e^- \rightleftharpoons \text{Cr}(s)$	-0.74
41. $\text{Zn}^{2+}(aq) + 2 e^- \rightleftharpoons \text{Zn}(s)$	-0.76
42. $\text{SO}_4^{2-}(aq) + \text{H}_2\text{O}(l) + 2 e^- \rightleftharpoons \text{SO}_3^{2-}(aq) + 2 \text{OH}^-(aq)$	-0.93
43. $\text{Al}^{3+}(aq) + 3 e^- \rightleftharpoons \text{Al}(s)$	-1.66
44. $\text{Al}(\text{OH})_4^-(aq) + 3 e^- \rightleftharpoons \text{Al}(s) + 4 \text{OH}^-(aq)$	-2.33
45. $\text{Mg}^{2+}(aq) + 2 e^- \rightleftharpoons \text{Mg}(s)$	-2.37

This information may or may not be needed.

NOTE: Due to the various ways of solving some problems, answers can differ by ± 1 in the final significant digit. Be aware of this.

Constants, Conversions $\text{mol} = 6.022 \times 10^{23}$
 $R = 0.08206 \text{ L} \cdot \text{atm}/(\text{mol} \cdot \text{K}) = 8.314 \text{ J}/(\text{mol} \cdot \text{K})$
 $T(\text{K}) = T(^{\circ}\text{C}) + 273$

Gas solubility $[A(aq)] = k_H \times P$

Standard Enthalpies of Formation (in kJ or kJ/mol)

$\text{Ca}^{2+}(aq)$ -542.83 $\text{CaCl}_2(s)$ -795.80 $\text{Cl}^{-}(aq)$ -167.16 $\text{NO}(g)$ 90.29

Standard Free Energies of Formation (in kJ or kJ/mol)

$\text{CH}_3\text{OH}(aq)$ -175.31 $\text{CO}_2(g)$ -394.39 $\text{HI}(g)$ 1.56
 $\text{H}_2\text{O}(l)$ -237.14 $\text{ICl}(g)$ -5.74 $\text{NO}(g)$ 86.60

Free Energy $\Delta G = \Delta G^{\circ} + RT \ln Q$
 $\Delta G^{\circ} = -RT \ln K$

First order kinetics $\ln \frac{[A]_0}{[A]_t} = akt$ $t_{1/2} = \frac{\ln 2}{ak}$

Second order kinetics $\frac{1}{[A]_t} - \frac{1}{[A]_0} = akt$ $t_{1/2} = \frac{1}{ak[A]_0}$

Quadratic Equation $x = \frac{-b \pm \sqrt{b^2 - 4ac}}{2a}$

K_a Values formic acid 1.8×10^{-4} HF 6.8×10^{-4}
 H_3PO_4 (1) 7.2×10^{-3} (2) 6.3×10^{-8} (3) 4.2×10^{-13}
 K_{sp} Values Ag_2CO_3 8.5×10^{-12} BaSO_4 1.1×10^{-10}

Henderson-Hasselbalch $\text{pH} = \text{p}K_a + \log \frac{\text{base}}{\text{acid}}$

Electrochemical $\Delta G^{\circ} = -nFE^{\circ}$
 $F = 96,485 \text{ C/mol}$
 $E = E^{\circ} - \frac{0.0257 \text{ V}}{n} \ln Q$

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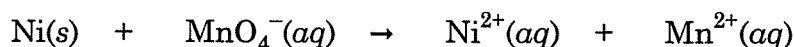
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Part 1. Newer Material

1. A buffer is composed of formic acid and its conjugate base, with $\text{pH} = 4.00$. What is the ratio of base to acid in this buffer?
(A) 0.26 (B) 0.59 (C) 0.95 (D) 1.5 (E) 1.8
2. A buffer solution contains 0.0237 mol sodium dihydrogen phosphate and 0.0165 mol of sodium hydrogen phosphate in a solution volume of 800. mL. What is the pH after 0.0022 mol HNO_3 is added to the solution?
(A) 6.74 (B) 6.81 (C) 6.94 (D) 7.07 (E) 7.10
3. Which statement is TRUE regarding the solubility of compounds in aqueous solution?
(A) Solubilities of solid, liquid and gaseous solutes typically increase in warmer solutions.
(B) The solubility of CO_2 in water is expressed with a K_{sp} value.
(C) Insoluble compounds do not dissolve in water to any extent.
(D) The equilibrium constant expression for dissolving $\text{NH}_3(\text{g})$ in water is $K = [\text{NH}_3]$.
(E) Most molecular compounds do not dissociate when they dissolve in water.
4. What is the simple solubility (in M) for silver carbonate?
(A) 2.6×10^{-5} (B) 4.0×10^{-5} (C) 8.7×10^{-5} (D) 1.3×10^{-4} (E) 3.6×10^{-4}
5. In which of the following will MgF_2 have the greatest solubility?
(A) 0.1 M NaOH (B) 0.1 M H_2SO_4 (C) 0.1 M MgCl_2
(D) 0.1 M NaF (E) pure water
6. What is the solubility of BaSO_4 in 0.10 M Na_2SO_4 solution?
(A) 4.3×10^{-11} (B) 2.8×10^{-10} (C) 1.1×10^{-9} (D) 6.5×10^{-8} (E) 2.9×10^{-7}

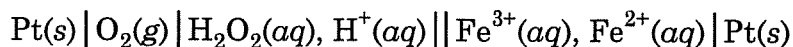
7. Which of the following statements is FALSE?
- (A) Lower charge ions give stronger associative effects in aqueous solution.
 - (B) The presence of a common ion in solution decreases the solubility of an ionic compound.
 - (C) Base dissociation effects for an anion, if significant, will increase the solubility of an ionic compound.
 - (D) Ion pairing is a type of associative equilibrium.
 - (E) The presence of strong acid in solution increases the solubility of calcium carbonate.

8. When the following (unbalanced!) equation is balanced and all coefficients are in lowest whole-number values, how many H^+ ions appear in the equation? (Assume acidic conditions.)



- (A) 0 (B) 1 (C) 5 (D) 8 (E) 16
9. The following half-reactions are not balanced. Which reaction equation represents an oxidation?
- (A) $\text{Sn}^{4+} \rightarrow \text{SnO}_2$ (B) $\text{Sn(OH)}_4 \rightarrow \text{Sn}^{2+}$ (C) $\text{H}_2\text{S} \rightarrow \text{HSO}_3^-$
 (D) $\text{MnO}_4^- \rightarrow \text{MnO}_2$ (E) $\text{H}^+ \rightarrow \text{H}_2$
10. Which of the following is the strongest reducing agent?
- (A) Al (B) Al^{3+} (C) Fe (D) Fe^{2+} (E) Fe^{3+}

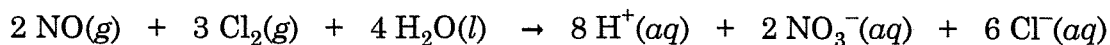
11. Consider the following cell notation.



Which of the following is the reducing agent?

- (A) $\text{Fe}^{3+}(\text{aq})$ (B) $\text{Fe}^{2+}(\text{aq})$ (C) $\text{O}_2(\text{aq})$ (D) $\text{H}^+(\text{aq})$ (E) $\text{H}_2\text{O}_2(\text{aq})$
12. For the cell given in Problem 11, what is E° (in V)?
- (A) 0.07 (B) -0.07 (C) 0.70 (D) -0.70 (E) 0.77

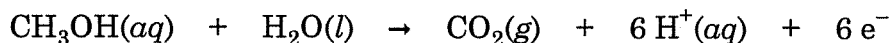
13. Consider a cell running the following overall reaction, starting at standard conditions.



Which of the following changes will give $E > E^\circ$?

- (A) $P(\text{NO}) = 0.5 \text{ atm}$ (B) $\text{pH} = 4.0$ in the anode half-cell (C) $[\text{NO}_3^-] = 2 \text{ M}$
(D) add NaCl to the cathode (E) increase the size of the electrodes

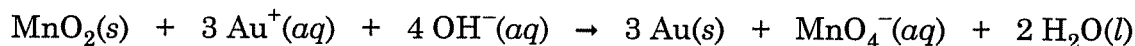
14. Methanol, CH_3OH , can be used in fuel cells. The half-cell reaction is the following.



Use free energies of formation to calculate the half-cell potential (in V).

- (A) -0.03120 (B) -0.08652 (C) -0.4531 (D) -0.9061 (E) -1.443

15. For the following reaction



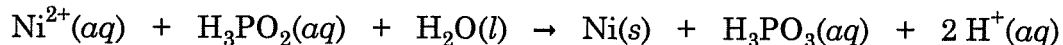
and the following conditions,

$$[\text{Au}^+] = 0.0354 \text{ M} \quad [\text{MnO}_4^-] = 0.129 \text{ M} \quad \text{pH} = 11.00$$

what is the value for E (in V)?

- (A) 0.78 (B) -0.78 (C) 1.09 (D) 1.40 (E) -1.40

16. For the following reaction



and the following conditions,

$$[\text{H}_3\text{PO}_3] = 0.516 \text{ M} \quad [\text{H}^+] = 1.00 \times 10^{-4} \text{ M} \quad [\text{H}_3\text{PO}_2] = 0.241 \text{ M} \quad E = 0.40 \text{ V}$$

what is the concentration (in M) of Ni^{2+} ?

- (A) 0.0036 (B) 0.0041 (C) 0.0055 (D) 0.0060 (E) 0.0072

17. Which of the following statements is FALSE?

- (A) For a spontaneous redox reaction, E and K are both positive, and ΔG is negative.
- (B) When $Q = K$, $E = 0$.
- (C) The value of E for a redox reaction changes with temperature.
- (D) If $Q > 1$, then $E > E^\circ$.
- (E) In an electrolytic cell, a nonspontaneous reaction occurs with an input of energy from outside the system.

18. Which of the following statements is TRUE?

- (A) The reduction half-reaction in a galvanic cell occurs at the anode.
- (B) The reduction half-reaction in an electrolytic cell occurs at the cathode.
- (C) An electrolytic reaction is exergonic.
- (D) A reaction in a galvanic cell is nonspontaneous.
- (E) A positive E corresponds to an endergonic reaction.

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Part 2. Older Material

26. How many grams of water are present in 1.00 L of air at 20. °C with 75% relative humidity? The EVP for H_2O at 20. °C is 17.5 Torr.

- (A) 0.010 (B) 0.013 (C) 0.016 (D) 0.019 (E) 0.022

27. Which of the following substances has the lowest normal boiling point?

- (A) HOOH (B) H_3CCl (C) H_3COH (D) H_2NNH_2 (E) CH_4

28. Which of the following statements is FALSE?
- (A) Na^+ has a lower charge density than Li^+ .
 - (B) Dissolving a gas into water is always exothermic.
 - (C) For any liquid solute dissolving into water, the enthalpy of solution is equal to the enthalpy of hydration.
 - (D) An exothermic enthalpy of solution favors dissolving.
 - (E) HF molecules can form hydrogen bonds with water molecules.
29. What is the value of $\Delta H^\circ_{\text{soln}}$ (in kJ) for $\text{CaCl}_2(\text{s})$?
- (A) -56.21 (B) -64.32 (C) -75.83 (D) -81.35 (E) -85.82
30. In order to form a more stable foam, some beer producers use N_2 gas instead of CO_2 gas. At equilibrium, how many grams of N_2 are dissolved in 12.0 oz (355 mL) of beer at 25 °C if the pressure of N_2 over the liquid is 3.0 atm? The value of k_{H} for N_2 is 0.00061 M/atm.
- (A) 0.0092 (B) 0.018 (C) 0.025 (D) 0.034 (E) 0.045
31. A 1.00 L solution was prepared containing 238 g sodium sulfate. The density was 1.191 g/mL. What was the molality of the sodium sulfate?
- (A) 0.583 (B) 0.827 (C) 1.17 (D) 1.43 (E) 1.76
32. Which of the following statements is FALSE?
- (A) The entropy of a system always increases as the temperature increases.
 - (B) The value of S° for $\text{H}^+(\text{aq})$ is set to zero.
 - (C) The standard molar entropy of $\text{CF}_4(\text{g})$ is greater than the standard molar entropy of $\text{C}_2\text{F}_6(\text{g})$.
 - (D) The formation reaction for $\text{ClO}_2(\text{g})$ has a negative ΔS° .
 - (E) Dissolving any gas into aqueous solution has a negative ΔS° .

33. Consider the following reaction.



For the following conditions (in atm), what is the value of ΔG (in kJ) at 25 °C?

$$P(\text{HI}) = 0.701 \quad P(\text{Cl}_2) = 0.164 \quad P(\text{H}_2) = 0.0520 \quad P(\text{ICl}) = 0.338$$

- (A) -8.63 (B) -12.07 (C) -21.06 (D) -27.18 (E) -42.65

34. Which of the following statements is FALSE?

- (A) The highest point on the reaction energy diagram for a simple mechanism represents the energy of the transition state.
- (B) A unimolecular step involves the collision of two particles of the same compound.
- (C) The intermediates of a composite mechanism do not appear in the overall balanced equation.
- (D) Values for k increase as temperature increases.
- (E) Faster reaction mechanisms give shorter half-lives.

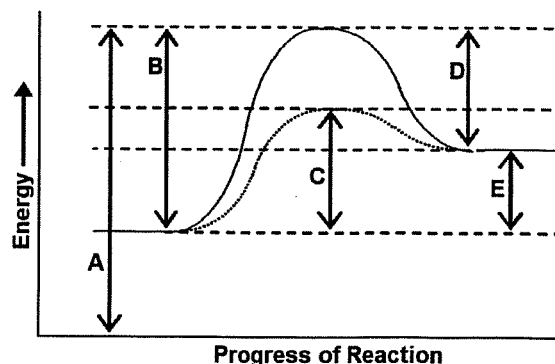
35. Consider the following reaction.



The reaction is second order in C_2H_2 ; at 770 K, $k = 0.178 \text{ L/mol/s}$. For a reaction which starts with $[\text{C}_2\text{H}_2] = 0.0241 \text{ mol/L}$, what is the percent completion after 50.0 s?

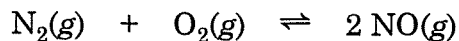
- (A) 11.6% (B) 29.9% (C) 35.2% (D) 46.9% (E) 52.8%

36. In the reaction energy diagram shown, the upper curve corresponds to the uncatalyzed reaction and the lower curve corresponds to the catalyzed reaction. Each arrow corresponds to an amount of energy. Which arrow (by letter) represents the activation energy for the reverse of the uncatalyzed reaction?



- (A) arrow A (B) arrow B (C) arrow C (D) arrow D (E) arrow E

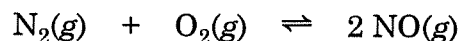
37. Consider the following equilibrium at 25 °C.



At sea level, air contains 0.78 atm of N_2 and 0.21 atm of O_2 . What is the equilibrium pressure (in atm) of NO in air under these conditions?

- (A) 2.7×10^{-16} (B) 1.6×10^{-15} (C) 7.8×10^{-14} (D) 4.1×10^{-13} (E) 5.3×10^{-12}

38. Consider the following equilibrium.



Which change to the reaction conditions below will increase the amount of NO which is present?

- (A) Increasing the pressure of the system by decreasing the volume of the container.
(B) Decreasing the pressure of the system by increasing the volume of the container.
(C) Adding an appropriate catalyst to the system.
(D) Increasing the temperature.
(E) Removing some of the O_2 .

39. What is the pH of 0.10 M KF?

- (A) 8.08 (B) 8.23 (C) 8.60 (D) 8.79 (E) 8.92

40. If each of the following salts is separately dissolved in water to make 0.1 M solutions, which solution will have the highest pH?

- (A) NH_4I (B) $\text{Ba}(\text{NO}_3)_2$ (C) KHSO_4 (D) Na_3PO_4 (E) MgBr_2