

**FORMULA SHEET (tear off)**

1A										8A																																			
1 H 1.01	2A										3A	4A	5A	6A	7A	2 He 4.00																													
3 Li 6.94	4 Be 9.01											5 B 10.81	6 C 12.01	7 N 14.01	8 O 16.00	9 F 19.00	10 Ne 20.18																												
11 Na 22.99	12 Mg 24.31											13 Al 26.98	14 Si 28.09	15 P 30.97	16 S 32.07	17 Cl 35.45	18 Ar 39.95																												
19 K 39.10	20 Ca 40.08	21 Sc 44.96	22 Ti 47.87	23 V 50.94	24 Cr 52.00	25 Mn 54.94	26 Fe 55.85	27 Co 58.93	28 Ni 58.69	29 Cu 63.55	30 Zn 65.41	31 Ga 69.72	32 Ge 72.64	33 As 74.92	34 Se 78.96	35 Br 79.90	36 Kr 83.80																												
37 Rb 85.47	38 Sr 87.62	39 Y 88.91	40 Zr 91.22	41 Nb 92.91	42 Mo 95.94	43 Tc [98]	44 Ru 101.1	45 Rh 102.9	46 Pd 106.4	47 Ag 107.9	48 Cd 112.4	49 In 114.8	50 Sn 118.7	51 Sb 121.8	52 Te 127.6	53 I 126.9	54 Xe 131.3																												
55 Cs 132.9	56 Ba 137.3	71 Lu 175.0	72 Hf 178.5	73 Ta 181.0	74 W 183.8	75 Re 186.2	76 Os 190.2	77 Ir 192.2	78 Pt 195.1	79 Au 197.0	80 Hg 200.6	81 Tl 204.4	82 Pb 207.2	83 Bi 209.0	84 Po [209]	85 At [210]	86 Rn [222]																												
87 Fr [223]	88 Ra [226]	103 Lr [262]	104 Rf [261]	105 Db [262]	106 Sg [266]																																								
<table border="1"> <tr> <td>57 La 138.9</td> <td>58 Ce 140.1</td> <td>59 Pr 140.9</td> <td>60 Nd 144.2</td> <td>61 Pm [145]</td> <td>62 Sm 150.4</td> <td>63 Eu 152.0</td> <td>64 Gd 157.2</td> <td>65 Tb 158.9</td> <td>66 Dy 162.5</td> <td>67 Ho 164.9</td> <td>68 Er 167.3</td> <td>69 Tm 168.9</td> <td>70 Yb 173.0</td> </tr> <tr> <td>89 Ac [227]</td> <td>90 Th 232.0</td> <td>91 Pa 231.0</td> <td>92 U 238.0</td> <td>93 Np [237]</td> <td>94 Pu [244]</td> <td>95 Am [243]</td> <td>96 Cm [247]</td> <td>97 Bk [247]</td> <td>98 Cf [251]</td> <td>99 Es [252]</td> <td>100 Fm [257]</td> <td>101 Md [258]</td> <td>102 No [259]</td> </tr> </table>																		57 La 138.9	58 Ce 140.1	59 Pr 140.9	60 Nd 144.2	61 Pm [145]	62 Sm 150.4	63 Eu 152.0	64 Gd 157.2	65 Tb 158.9	66 Dy 162.5	67 Ho 164.9	68 Er 167.3	69 Tm 168.9	70 Yb 173.0	89 Ac [227]	90 Th 232.0	91 Pa 231.0	92 U 238.0	93 Np [237]	94 Pu [244]	95 Am [243]	96 Cm [247]	97 Bk [247]	98 Cf [251]	99 Es [252]	100 Fm [257]	101 Md [258]	102 No [259]
57 La 138.9	58 Ce 140.1	59 Pr 140.9	60 Nd 144.2	61 Pm [145]	62 Sm 150.4	63 Eu 152.0	64 Gd 157.2	65 Tb 158.9	66 Dy 162.5	67 Ho 164.9	68 Er 167.3	69 Tm 168.9	70 Yb 173.0																																
89 Ac [227]	90 Th 232.0	91 Pa 231.0	92 U 238.0	93 Np [237]	94 Pu [244]	95 Am [243]	96 Cm [247]	97 Bk [247]	98 Cf [251]	99 Es [252]	100 Fm [257]	101 Md [258]	102 No [259]																																

$$N_A = 6.022 \times 10^{23}$$

$$1 \text{ amu} = 1.661 \times 10^{-27} \text{ kg}$$

$$1 \text{ atm} = 760 \text{ torr} = 760 \text{ mm Hg}$$

$$R = 0.08206 \text{ L}\cdot\text{atm}/\text{mol}\cdot\text{K}$$

$$R = 8.314 \text{ J}/\text{mol}\cdot\text{K}$$

$$F = 96485 \text{ C}/\text{mol}$$

$$^{\circ}\text{C} = (5/9)(^{\circ}\text{F} - 32)$$

$$^{\circ}\text{C} = \text{K} - 273.15$$

$$1 \text{ atm} = 1.013 \text{ bar}$$

$$1 \text{ L}\cdot\text{atm} = 101.3 \text{ J}$$

$$1 \text{ J} = 1 \text{ kg}\cdot\text{m}^2/\text{s}^2$$

$$(1 \text{ volt}) \cdot (1 \text{ Coulomb}) = 1 \text{ Joule}$$

$$^{\circ}\text{F} = (9/5)(^{\circ}\text{C}) + 32$$

$$\text{K} = ^{\circ}\text{C} + 273.15$$

$$pV = nRT$$

$$p_A = X_A p_A^{\circ}$$

$$\Delta T_b = K_b m_B$$

$$H = U + pV$$

$$\Delta G_{\text{rxn}} = \Delta G^{\circ}_{\text{rxn}} + RT \ln Q$$

$$\text{If } ax^2 + bx + c = 0, \text{ then } x = \left( \frac{-b \pm [b^2 - 4ac]^{1/2}}{2a} \right)$$

$$K_a \cdot K_b = K_w$$

$$K_a \cdot K_b = 1.0 \times 10^{-14} \text{ (at } T = 25. ^{\circ}\text{C)}$$

$$\text{pH} = \text{p}K_a + \log_{10}\left\{ \frac{[\text{base}]}{[\text{acid}]} \right\}$$

$$\Delta G = -nFE_{\text{cell}}$$

$$[A]_t = [A]_0 e^{-kt}$$

$$[A]_t = \frac{[A]_0}{(1 + kt[A]_0)}$$

$$k = A e^{-E_a/RT}$$

$$[B] = k p_B$$

$$\Delta T_f = K_f m_B$$

$$G = H - TS$$

$$\ln K = -\frac{\Delta G^{\circ}_{\text{rxn}}}{RT}$$

$$\ln K = -\frac{\Delta G^{\circ}_{\text{rxn}}}{RT}$$

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

$$\ln[A]_t = \ln[A]_0 - kt$$

$$\frac{1}{[A]_t} = \frac{1}{[A]_0} + kt$$

$$\ln k = \ln A - (E_a/R)(1/T)$$

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

$$\ln[A]_t = \ln[A]_0 - kt$$

$$\frac{1}{[A]_t} = \frac{1}{[A]_0} + kt$$

$$\ln k = \ln A - (E_a/R)(1/T)$$

$$\Delta p_A = X_B p_A^{\circ}$$

$$\Pi = M_B RT$$

$$K_p = K_C (RT)^{\Delta n_g}$$

$$\ln K = \frac{nFE^{\circ}_{\text{cell}}}{RT}$$

$$\ln K = \frac{nFE^{\circ}_{\text{cell}}}{RT}$$

$$\text{pH} + \text{pOH} = \text{p}K_w$$

$$\text{pH} + \text{pOH} = 14.00 \text{ (at } T = 25. ^{\circ}\text{C)}$$

$$\ln K = \frac{nFE^{\circ}_{\text{cell}}}{RT}$$

$$\ln K = \frac{nFE^{\circ}_{\text{cell}}}{RT}$$

$$t_{1/2} = (\ln 2)/k$$

$$t_{1/2} = 1/(k[A]_0)$$

$$\ln(k_2/k_1) = - (E_a/R) \left[ (1/T_2) - (1/T_1) \right]$$

**GENERAL CHEMISTRY 2  
FINAL EXAM  
APRIL 25, 2022**

**Name** \_\_\_\_\_

**Panthersoft ID** \_\_\_\_\_

**Signature** \_\_\_\_\_

**Part 1** \_\_\_\_\_ (50 points)

**Part 2** \_\_\_\_\_ (82 points)

**Part 3** \_\_\_\_\_ (68 points)

**TOTAL** \_\_\_\_\_ (200 points)

**Do all of the following problems. Show your work.**  
**Unless otherwise stated, you may assume  $T = 25. \text{ }^{\circ}\text{C}$  in all problems.**

**Part 1. Multiple choice.** Circle the letter corresponding to the correct answer. There is one and only one correct answer per problem. [5 points each]

1) Consider a nonpolar liquid such as carbon tetrachloride ( $\text{CCl}_4$ ). Which general types of solids would be expected to usually be soluble in such a liquid?

- a) Polar molecular solid
- b) Non-polar molecular solid
- B** c) Ionic solid
- d) Both a and c
- e) Both b and c

2) For a chemical reaction to be spontaneous for standard conditions which of the following must be true?

- a)  $\Delta S^\circ_{\text{syst}} > 0$
- b)  $\Delta S^\circ_{\text{surr}} > 0$
- C** c)  $\Delta S^\circ_{\text{univ}} > 0$
- d) Both a and b
- e) Both a and b and c

3) For which of the following reactions can an expression for  $K_p$  be written?

- a)  $\text{CO}_2(\text{g}) + \text{H}_2\text{O}(\ell) \rightleftharpoons \text{H}_2\text{CO}_3(\text{aq})$
- b)  $\text{H}_2(\text{g}) + \text{I}_2(\text{s}) \rightleftharpoons 2 \text{HI}(\text{g})$
- B** c)  $\text{NH}_3(\text{aq}) + \text{H}_2\text{O}(\ell) \rightleftharpoons \text{NH}_4^+(\text{aq}) + \text{OH}^-(\text{aq})$
- d) Both a and b
- e) None of the above

4) For the chemical reaction



$K_C = 2.9 \times 10^4$  at  $T = 400.^\circ\text{C}$ . In a closed system containing  $\text{CH}_2\text{O}$ ,  $\text{CO}$ , and  $\text{H}_2$  at  $400.^\circ\text{C}$  the value for the reaction quotient is  $Q = 2.0 \times 10^6$ . As the system approaches equilibrium, which of the following will occur?

- a) The moles of  $\text{H}_2\text{CO}$  in the system will increase
- b) The moles of  $\text{CO}$  in the system will increase
- A** c) The moles of  $\text{H}_2$  in the system will increase
- d) Both b and c
- e) Both a and b and c

5) A Bronsted base is

- a) an electron pair donor
- b) a proton donor
- D** c) an electron pair acceptor
- d) a proton acceptor
- e) an amphoteric substance

6) For which type of titration will the pH at the equivalence point be expected to be less than 7.0?

- a) The titration of a strong acid with a strong base
- b) The titration of a weak acid with a strong base
- E** c) The titration of a strong base with a strong acid
- d) Both a and b
- e) None of the above

7) The solubility product for four slightly soluble ionic compounds containing hydroxide ion ( $\text{OH}^-$ ) are given below



Which of the above compounds would have the highest molar solubility when added to a pH = 10.00 buffer?

- A
- a)  $\text{Co}(\text{OH})_2$
  - b)  $\text{Ni}(\text{OH})_2$
  - c)  $\text{Pb}(\text{OH})_2$
  - d)  $\text{Zn}(\text{OH})_2$
  - e) All four compounds would have the same molar solubility when added to a pH = 10.00 buffer

8) In a galvanic cell

- A
- a) oxidation occurs at the anode
  - b) reduction occurs at the anode
  - c) oxidation occurs at the cathode
  - d) Both a and c
  - e) Both b and c

9) A particular irreversible chemical reaction follows the following rate law:  $\text{rate} = k [\text{A}] [\text{B}]$ . The rate law is

- D
- a) first order in A
  - b) first order in B
  - c) a homogeneous rate law
  - d) Both a and b
  - e) Both a and b and c

10) In the Arrhenius equation, the value for the pre-exponential factor A depends on

- D
- a) the collision frequency
  - b) the orientation of the reactant molecules when they collide
  - c) the height of the energy barrier separating reactant and product molecules
  - d) Both a and b
  - e) Both a and b and c

## Part 2. Short answer.

1) Short answer questions. For each of the following questions given the correct answer by filling in the blank. [5 points each]

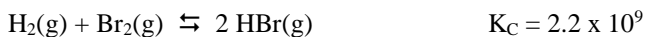
a) The conjugate acid of methylamine ( $\text{CH}_3\text{NH}_2$ ).  $\text{CH}_3\text{NH}_3^+$

b) The oxidation number for an atom in an elemental form of a pure chemical substance. 0

c) An expression for the average rate of reaction for the process  $2 \text{H}_2(\text{g}) + \text{O}_2(\text{g}) \rightarrow 2 \text{H}_2\text{O}(\text{g})$ , in terms of formation of product.

$$\text{average rate} = \frac{1}{2} \frac{\Delta[\text{H}_2\text{O}]}{\Delta t} = \frac{1}{2} \frac{[\text{H}_2\text{O}]_2 - [\text{H}_2\text{O}]_1}{t_2 - t_1}$$

2) At room temperature, hydrogen and bromine gas exist in equilibrium with hydrogen bromide



A system initially contains 0.0080 mol/L  $\text{H}_2$  and 0.0260 mol/L  $\text{HBr}$ . There is no  $\text{Br}_2$  initially present. Find  $[\text{Br}_2]$ , the concentration of bromine (in mol/L) when equilibrium is reached. [12 points]

$K_C = \frac{[\text{HBr}]^2}{[\text{H}_2][\text{Br}_2]}$	Initial	Change	Equilibrium
$\text{H}_2$	0.0080	x	$0.0080 + x$
$\text{Br}_2$	0	x	x
$\text{HBr}$	0.0260	- 2x	$0.0260 - 2x$

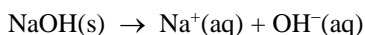
So  $\frac{(0.0260 - 2x)^2}{(0.0080 + x)(x)} = 2.2 \times 10^9$       Assume  $x \ll 0.0080$ , then

$$\frac{(0.0260)^2}{(0.0080)x} = 2.2 \times 10^9 \quad x = \frac{(0.0260)^2}{(0.0080)(2.2 \times 10^9)} = 3.8 \times 10^{-11} \quad \text{So } x \ll 0.0080$$

Therefore, at equilibrium  $[\text{Br}_2] = 3.8 \times 10^{-11}$  mol/L

3) Find the pH for each of the following solutions [10 points each]

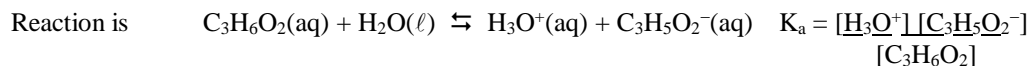
a) A 0.0590 M solution of sodium hydroxide ( $\text{NaOH}$ ), a strong soluble base.



So  $[\text{OH}^-] = 0.0590 \text{ M NaOH} \frac{1 \text{ mol OH}^-}{1 \text{ mol NaOH}} = 0.0590 \text{ M OH}^-$

$\text{pOH} = -\log_{10}[\text{OH}^-] = -\log_{10}(0.0590) = 1.23$        $\text{pH} = 14.00 - \text{pOH} = 14.00 - 1.23 = 12.77$

b) A 0.0860 M solution of propanoic acid ( $\text{C}_3\text{H}_6\text{O}_2$ ), a weak acid, with  $K_a = 1.35 \times 10^{-5}$



	Initial	Change	Equilibrium
$\text{H}_3\text{O}^+$	0	x	x
$\text{C}_3\text{H}_5\text{O}_2^-$	0	x	x
$\text{C}_3\text{H}_6\text{O}_2$	0.0860	- x	$0.0860 - x$

So  $\frac{(x)(x)}{(0.0860 - x)} = 1.35 \times 10^{-5}$       Assume  $x \ll 0.0860$ , then

$$\frac{x^2}{0.0860} = 1.35 \times 10^{-5} \quad x^2 = (0.0860)(1.35 \times 10^{-5}) = 1.16 \times 10^{-6}$$

$$x = (1.16 \times 10^{-6})^{1/2} = 1.07 \times 10^{-3} \quad \text{So } x \ll 0.0860$$

So  $[\text{H}_3\text{O}^+] = x = 1.07 \times 10^{-3}$        $\text{pH} = -\log_{10}[\text{H}_3\text{O}^+] = -\log_{10}(1.07 \times 10^{-3}) = 2.97$

4) A student prepares a buffer solution at pH = 4.80. The buffer uses acetic acid (CH<sub>3</sub>COOH) as the weak acid, and acetate ion (CH<sub>3</sub>COO<sup>-</sup>) as the conjugate base of the weak acid.

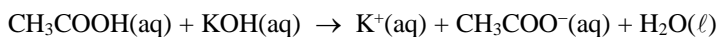
a) What are pOH, [H<sub>3</sub>O<sup>+</sup>], and [OH<sup>-</sup>] for the buffer solution? [10 points]

$$\text{pOH} = 14.00 - \text{pH} = 14.00 - 4.80 = 9.20$$

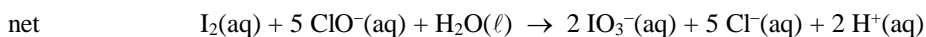
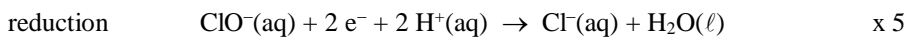
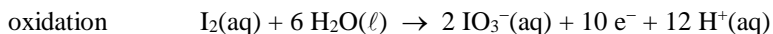
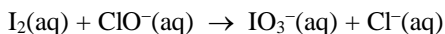
$$[\text{H}_3\text{O}^+] = 10^{-\text{pH}} = 10^{-4.80} = 1.6 \times 10^{-5} \text{ M}$$

$$[\text{OH}^-] = 10^{-\text{pOH}} = 10^{-9.20} = 6.3 \times 10^{-10}$$

b) Give the balanced chemical reaction that takes place when a small amount of KOH (a strong soluble base) is added to the buffer solution. [5 points]



5) Balance the following unbalanced oxidation-reduction reaction for acid conditions. [12 points]



6) For a particular first order irreversible homogeneous reaction, the half-life of the reaction is found to be  $t_{1/2} = 47.8$  minutes. What is the value for  $k$  for the reaction (including correct units)? [8 points]

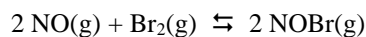
$$t_{1/2} = \frac{\ln(2)}{k} \quad k = \frac{\ln(2)}{t_{1/2}} = \frac{\ln(2)}{47.8 \text{ min}} = 0.0145 \text{ min}^{-1}$$

### Part 3. Problems.

1) Thermodynamic data are given below (at  $T = 25. \text{ }^\circ\text{C}$ ) and may be of use in doing this problem.

Substance	$\Delta H^\circ_f$ (kJ/mole)	$\Delta G^\circ_f$ (kJ/mole)	$S^\circ$ (J/mole·K)
$\text{Br}_2(\text{g})$	30.9	3.1	245.5
$\text{NO}(\text{g})$	91.3	87.6	210.8
$\text{NOBr}(\text{g})$	82.2	82.4	273.7

Nitrosyl bromide (NOBr) can be formed from the reaction of bromine gas with nitrogen monoxide. The balanced equation for the reaction is



a) Find the numerical values for  $\Delta S^\circ_{\text{rxn}}$ ,  $\Delta G^\circ_{\text{rxn}}$ , and  $K$  (the thermodynamic equilibrium constant) for the above reaction. [18 points]

$$\begin{aligned}\Delta S^\circ_{\text{rxn}} &= [ 2 S^\circ(\text{NOBr}(\text{g})) ] - [ 2 S^\circ(\text{NO}(\text{g})) + S^\circ(\text{Br}_2(\text{g})) ] \\ &= [ 2 (273.7) ] - [ 2 (210.8) + (245.5) ] = - 119.7 \text{ J/mol}\cdot\text{K}\end{aligned}$$

$$\begin{aligned}\Delta G^\circ_{\text{rxn}} &= [ 2 \Delta G^\circ_f(\text{NOBr}(\text{g})) ] - [ 2 \Delta G^\circ_f(\text{NO}(\text{g})) + \Delta G^\circ_f(\text{Br}_2(\text{g})) ] \\ &= [ 2 (82.4) ] - [ 2 (87.6) + (3.1) ] = - 13.5 \text{ kJ/mol}\end{aligned}$$

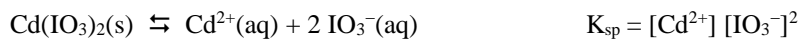
$$\ln K = - \frac{\Delta G^\circ_{\text{rxn}}}{RT} = - \frac{(-13500. \text{ J/mol})}{(8.3145 \text{ J/mol}\cdot\text{K}) (298.2 \text{ K})} = 5.44 \quad K = e^{5.44} = 232.$$

b) Is the above reaction spontaneous for standard conditions (yes/no and a brief justification of your answer)? [6 points]

Yes, because  $\Delta G^\circ_{\text{rxn}} < 0$ .

2) Cadmium II iodate ( $\text{Cd}(\text{IO}_3)_2$ ,  $\text{MW} = 462.2 \text{ g/mol}$ ) is a slightly soluble ionic compound.

a) Give the correctly balanced equation for the solubility reaction for cadmium II iodate in water. Also give the expression for  $K_{\text{sp}}$ , the solubility product. [8 points]



b) The osmotic pressure of a saturated solution of cadmium II iodate, measured at  $T = 25.0 \text{ }^\circ\text{C}$ , is  $\Pi = 104.$  torr. Based on this result, find the numerical value for  $K_{\text{sp}}$ , the solubility product of cadmium II iodate. [16 points]

$\Pi = M_{\text{B}}RT$ , where  $M_{\text{B}}$  is the molarity of solute particles

$$M_{\text{B}} = \frac{\Pi}{RT} = \frac{104. \text{ torr} (1 \text{ atm}/760. \text{ torr})}{(0.08206 \text{ L}\cdot\text{atm}/\text{mol}\cdot\text{K}) (298.2 \text{ K})} = 5.59 \times 10^{-3} \text{ M}$$

If we call  $[\text{Cd}^{2+}] = x$ , then  $[\text{IO}_3^{-}] = 2x$

$$M_{\text{B}} = [\text{Cd}^{2+}] + [\text{IO}_3^{-}] = x + 2x = 3x \quad x = \frac{M_{\text{B}}}{3} = \frac{5.59 \times 10^{-3}}{3} = 1.86 \times 10^{-3} \text{ M}$$

$$K_{\text{sp}} = (x) (2x)^2 = 4x^3 = 4 (1.86 \times 10^{-3})^3 = 2.6 \times 10^{-8}$$



3) A particular irreversible chemical reaction obeys the rate law

$$\text{rate} = k [\text{A}]^m [\text{B}]^n$$

The initial rate of reaction is measured for a variety of initial conditions, and the data are given below. All experiments were carried out at the same temperature. Based on this information, find the values for m, n, and k (including correct units). [20 points]

experiment	[A] (mol/L)	[B] (mol/L)	initial rate (mol/L·s)
1	0.0200	0.0200	$0.88 \times 10^{-6}$
2	0.0200	0.0500	$5.54 \times 10^{-6}$
3	0.0100	0.0200	$0.42 \times 10^{-6}$

For m, compare experiments 1 and 3

$$\frac{R_1}{R_3} = \frac{k [\text{A}]_1^m [\text{B}]_1^n}{k [\text{A}]_3^m [\text{B}]_3^n} = \left( \frac{[\text{A}]_1}{[\text{A}]_3} \right)^m$$

$$(0.88/0.42) = (0.0200/0.0100)^m \quad 2.10 = 2^m \quad m = 1$$

For n, compare experiments 2 and 1

$$\frac{R_2}{R_1} = \frac{k [\text{A}]_2^m [\text{B}]_2^n}{k [\text{A}]_1^m [\text{B}]_1^n} = \left( \frac{[\text{B}]_2}{[\text{B}]_1} \right)^n$$

$$(5.54/0.88) = (0.0500/0.0200)^n \quad 6.30 = (2.5)^n \quad n = 2$$

So the rate law is  $R = k [\text{A}] [\text{B}]^2$

$$k = \frac{R}{[\text{A}] [\text{B}]^2}$$

Using the data for experiment 1  $k = \frac{0.88 \times 10^{-6} \text{ mol/L}\cdot\text{s}}{(0.0200 \text{ mol/L}) (0.0200 \text{ mol/L})^2} = 0.110 \text{ L}^2/\text{mol}^2\cdot\text{s}$