SCH4U1 Equilibrium Test Review Ch. 7 **Name** Answers **Date** _____

1. Complete the following table, based on the following equilibrium system. (6 marks)

$2Cl_{2(g)} + 2H_2O_{(g)} \leftrightarrow 4HCl_{(g)} + O_{2(g)}$ $\Delta H = -133$ kJ exothermic

4 5

Stress	Equilibrium shift (to the right or left?)
increase in temperature	Left
increase in hydrogen chloride	Left
decrease in pressure	Right
decrease in volume	Left
addition of a catalyst	No shift
decrease in oxygen gas	Right

2. For the following reaction, $H_2 + I_2 \leftrightarrow 2HI$, where Kc = 57, calculate the reaction quotient, Q_c, and predict the direction the reaction will shift if the following concentrations are present: [HI] = 0.40 M; [H2] = 0.10 M; [I2] = 0.20 M [4 marks]

$Q = \frac{[HI]^2}{[H_2][I_2]} = \frac{(0.4)^2}{(0.1)(0.2)} = 8$

$Q_c < K_c$

$8 < 57$

∴ shift right

3. Under a given set of conditions, an equilibrium mixture

$SO_2(g) + NO_2 <===> SO_3(g) + NO(g)$

in a 2.00 L container was analyzed and found to contain 0.300 mole of SO_3, 0.200 mole of NO, 0.0500 mole of NO_2, and 0.400 mole of SO_2. Calculate the equilibrium constant for this reaction. [4]

	SO_2	+ NO_2	↔ SO_3	+ NO
E	$\frac{0.4}{2}$	$\frac{0.05}{2}$	$\frac{0.3}{2}$	$\frac{0.2}{2}$
	= 0.2	= 0.025	= 0.15	= 0.1 mol/L

$K_c = \frac{[SO_3][NO]}{[SO_2][NO_2]} = \frac{(0.15)(0.1)}{(0.2)(0.025)} = 3$

4. The following equilibrium system has an equilibrium constant of 5.2×10^3. Find the equilibrium concentration of each species if 0.500 mol of $H_2O_{(g)}$ and 0.500 mol of $Cl_2O_{(g)}$ are allowed to come to equilibrium in a 1 L container. [5]

$H_2O_{(g)} + Cl_2O_{(g)} \leftrightarrow 2HOCl_{(g)}$

	H_2O	+ Cl_2O	↔ 2HOCl
I	0.5	0.5	0
C	−x	−x	+2x
E	0.5 − x	0.5 − x	2x

$K_a = \frac{[HOCl]^2}{[H_2O][Cl_2O]}$

$5.2 \times 10^3 = \frac{(2x)^2}{(0.5-x)^2}$

$7.211 = \frac{2x}{0.5-x}$

$7.211(0.5 - x) = 2x$

$36.0555 - 7.211x = 2x$

$36.0555 = 9.211x$

$x = 0.4865$

$[H_2O] = 0.5 - 0.4865 = 0.0135$ mol/L

$[HOCl] = 2(0.4865) = 0.973$ mol/L

5. At a certain temperature, the following equilibrium mixture is formed.

$2CO_{(g)} + O_{2(g)} \leftrightarrow 2CO_{2(g)}$

The value of the equilibrium constant at this temperature is 1.00×10^{-3}. Determine the equilibrium concentration of each component if initially 1.00 mol of $CO_{(g)}$ and 1.00 mol of $O_{2(g)}$ are placed in a 2.00 L reaction vessel for the reaction to proceed. [6]

	2 CO	+ O_2	↔ $2CO_2$
I	1	0.5	0
C	−2x	−x	+2x
E	0.5 − 2x	0.5 − x	2x
	= 0.5 − 2(5.59×10⁻³)	= 0.5 − 5.59×10⁻³	2x = 2(5.59×10⁻³)
	= 0.489 mol/L	= 0.494 mol/L	= 0.01118 mol/L

$K_c = \frac{[CO_2]^2}{[CO]^2[O_2]}$

$1 \times 10^{-3} = \frac{(2x)^2}{(0.5-2x)^2(0.5-x)}$ omit

$1 \times 10^{-3} = \frac{4x^2}{(0.5)(0.5)}$

$\frac{1.25 \times 10^{-4}}{4} = \frac{4x^2}{4}$

$x^2 = 3.125 \times 10^{-5}$

$x = 5.59 \times 10^{-3}$

check

$\frac{0.5}{1 \times 10^{-3}} > 100$

∴ approx

SCH4U1 Ch. 8 & 9 Equilibrium Test Review **Name**_____

Multiple Choice: *Identify the letter of the choice that best completes the statement or answers the question.*

d 1. What is the Arrhenius definition of an acid?
   a. a substance that donates protons
   b. a substance that accepts protons
   c. a substance that dissolves in water to form OH^- ions
   d. a substance that dissolves in water to form H^+ ions
   e. none of the above

b 2. What is the Brønstead-Lowry definition of a base?
   a. a substance that donates protons
   b. a substance that accepts protons
   c. a substance that dissolves in water to form OH^- ions
   d. a substance that dissolves in water to form H^+ ions
   e. none of the above

d 3. Which compound is the strongest acid?
   a. $HIO_{3(aq)}$
   b. $HClO_{(aq)}$
   c. NaOH
   d. $HClO_{4(aq)}$
   e. $HC_2H_3O_{2(aq)}$

d 4. Which compound is not a strong base?
   a. barium hydroxide
   b. cesium hydroxide
   c. sodium hydroxide
   d. ammonium hydroxide
   e. magnesium hydroxide

c 5. Which term describes a substance that acts as a proton donor and a proton acceptor?
   a. acid-base
   b. buffer
   c. amphoteric
   d. polyprotic
   e. Monoprotic

e 6. What is the most important factor for determining the strength of binary acids across a period in the periodic table?
   a. number of oxygen atoms
   b. size of the nucleus
   c. number of hydrogen atoms
   d. strength of the bond
   e. electronegativity

d 7. Based on your knowledge of the relative strength of oxyacids, which acid is the strongest acid?
   a. $HIO_{(aq)}$
   b. $HIO_{2(aq)}$
   c. $HIO_{3(aq)}$
   d. $HIO_{4(aq)}$
   e. These acids are all the same strength.

c 8. What is the concentration of hydroxide ions in a solution of 0.350 mol/L $HI_{(aq)}$?
   a. 1.30 mol/L
   b. 0.650 mol/L
   c. 2.86×10^{-14} mol/L
   d. 0.350 mol/L
   e. 0.175 mol/L

$HI \rightarrow H^+ + I^-$
$.35 \quad .35 \quad .35$
$pH = -\log(.35) = 0.456$
$pOH = 13.544$
$[OH] = 10^{-pOH} = 2.86 \times 10^{-14}$

b 9. A solution contains 6.3×10^{-5} hydronium ions. What is the pH of the solution?
   a. 9.80
   b. 4.20
   c. 6.30
   d. 5.00
   e. 8.10

$pH = -\log[H_3O^+]$

b 10. A solution contains 3.25×10^{-8} hydroxide ions. What is the pH of the solution?

a. 3.25
b. 6.51
c. 7.49
d. 8.00
e. none of the above

$pOH = -\log[OH^-]$
$= 7.49$
$pH = 14 - 7.5 = 6.51$

d 11. A solution has a pOH of 5.23. What is the concentration of hydroxide ions in the solution?

a. 1.0×10^{-14}
b. 1.7×10^{-9}
c. 1.0×10^{-7}
d. 5.9×10^{-6}
e. none of the above

$10^{-5.23} = 5.89 \times 10^{-6}$

b 12. A solution has a pH of 4.65. What is the concentration of hydroxide ions in the solution?

a. 1.0×10^{-14}
b. 4.5×10^{-10}
c. 1.0×10^{-7}
d. 2.2×10^{-5}
e. none of the above

$pOH = 14 - 4.65$
$= 9.35$
$[OH^-] = 10^{-9.35}$
$= 4.47 \times 10^{-10}$

a 13. Identify the weakest acid.

a. HCN $K_a = 6.2 \times 10^{-10}$
b. HCOOH $K_a = 1.8 \times 10^{-4}$
c. HNO_2 $K_a = 7.2 \times 10^{-4}$
d. HF $K_a = 6.6 \times 10^{-4}$
e. All acids are the same strength, as long as they have a dissociable hydrogen ion.

b 14. What is the relationship between the ion product, Q_{sp}, and the solubility product, K_{sp}, constants when a precipitate forms?

a. $Q_{sp} < K_{sp}$
b. $Q_{sp} > K_{sp}$
c. $Q_{sp} = K_{sp}$
d. $Q_{sp} \geq K_{sp}$
e. $Q_{sp} \geq K_{sp}$

omit 17. A weak acid ($K_a = 4.5 \times 10^{-5}$) is neutralized with a weak base ($K_b = 5.6 \times 10^{-8}$). What is the pH of the resulting solution?

a. pH = 7
b. acidic
c. neutral
d. basic
e. pH = 3.2

e 15. What is the solubility product constant for lead(II) bromide?

a. $[Pb^{2+}][Br^-]$
b. $\dfrac{[Pb^{2+}][Br^-]^2}{[PbBr_2]}$
c. $\dfrac{[Pb^{2+}][Br^-]}{[PbBr_2]}$
d. $\dfrac{[PbBr_2]}{[Pb^{2+}][Br^-]^2}$
e. $[Pb^{2+}][Br^-]^2$

$PbBr_2 \rightarrow Pb^{+2} + 2Br^-$
$= [Pb^{+2}][Br^-]^2$

d 16. 9.54×10^{-4} mol/L is the solubility of lead(II) iodide in water at 0°C. What is the solubility product constant for lead(II) iodide at the same temperature?

a. 1.82×10^{-6}
b. 9.54×10^{-4}
c. 9.10×10^{-7}
d. 3.48×10^{-9}
e. 8.68×10^{-10}

$K_{sp} = [Pb^{+2}][I^-]^2$
$= (9.54 \times 10^{-4})(2(9.54 \times 10^{-4}))^2$
$= 3.47 \times 10^{-9}$

$PbI_2 \leftrightarrow Pb^{+2} + 2I^-$
$9.54 \times 10^{-4} \quad 9.54 \times 10^{-4} \quad 2(9.54 \times 10^{-4})$

b 17. The solubility of iron(II) carbonate is 6.7×10^{-3} g/100 mL at 25°C. What is this solubility in mol/L?

a. 3.8×10^{-5} mol/L
b. 5.9×10^{-4} mol/L
c. 3.8×10^{-4} mol/L
d. 6.7×10^{-3} mol/L
e. 5.9×10^{-5} mol/L

$= .1$ L

$FeCO_3$ $55.85 + 12 + 48$

$= 115.85$ ⇒ 5.78×10^{-4}

$n = 5.78 \times 10^{-5}$

b 18. The solubility product constant for lithium carbonate is 1.7×10^{-3} at 25°C. What is the molar solubility of lithium carbonate at this temperature?

a. 0.12 mol/L
b. 0.075 mol/L
c. 0.041 mol/L
d. 0.095 mol/L
e. 0.0017 mol/L

$K_{sp} = 1.7 \times 10^{-3}$

$Li_2CO_3 \rightarrow 2Li^+ + CO_3^{-2}$

$K_{sp} = [Li^+]^2[CO_3^{-2}]$ $\quad 2s \quad s$ $\quad 1.7 \times 10^{-3} = (2s)^2(s) = 4s^3$

Short Answer

22. Use the concept of equilibrium to explain the difference between a weak acid and a strong acid.

$s^3 = 4.25 \times 10^{-4}$

$s = 7.5 \times 10^{-2}$

23. Label the conjugate acid-base pairs in each reaction.
a) $NH_{3(aq)} + H_2O_{(l)} \rightarrow NH_4^+{}_{(aq)} + OH^-{}_{(aq)}$
b) $HF_{(aq)} + H_2O_{(l)} \rightarrow H_3O^+{}_{(aq)} + F^-{}_{(aq)}$

24. Using the concept of equilibrium, explain the behaviour of an ionic solute in a saturated solution.

Problems

25. A solution of hydrocyanic acid has an initial concentration of 5.0×10^{-3} mol/L.
a) What are the concentrations of the ions at equilibrium, if $K_a = 4.9 \times 10^{-10}$.
b) What is the solution's pH at equilibrium?

26. Lactic acid, $C_3H_6O_3$, builds up in human muscles during anaerobic exercise. If the initial concentration of lactic acid is 0.12 mol/L and the pH is 2.39, what is K_a for lactic acid?

27. Determine the Ka for butanoic acid, given that the pH of a 0.0240 mol/L solution of this acid is 3.22 and it is a monoprotic acid.

28. Calculate the pH of a 2.41×10^{-5} mol/L solution of $Al(OH)_3$.

29. The pH of a 0.455 mol/L hypoiodous acid solution, $HIO_{(aq)}$, is 1.502. What is the equilibrium constant (Ka) for this acid?

30. 50.0 mL of 0.0015 mol/L calcium chloride solution is added to 75.0 mL of 0.010 mol/L sodium sulfate solution ($K_{sp} = 2.0 \times 10^{-4}$). Does a precipitate of calcium sulfate form?

OMIT 31. Determine if a precipitate will form when 250 mL 0.15 mol/L KF solution is mixed with 150 mL of 0.015 mol/L $BaCl_2$ solution.

SHORT ANSWER

22. ANS:
The strength of an acid is related to the value of the equilibrium constant of the acid in an aqueous solution. Strong acids have equilibrium constants that are greater than 1 and ionize completely.

23. ANS:

a) $NH_{3(aq)}$ + $H_2O_{(l)}$ Û $NH_4^+{}_{(aq)}$ + $OH^-{}_{(aq)}$
base 1 acid 2 conjugate acid 1 conjugate base 2

b) $HF_{(aq)}$ + $H_2O_{(l)}$ Û $H_3O^+{}_{(aq)}$ + $F^-{}_{(aq)}$
acid 1 base 2 conjugate acid 2 conjugate base 1

24. ANS:
In a saturated solution, the ions of the solute have separated and become surrounded by water molecules until the maximum amount of solute has dissolved. If some solute remains undissolved, an equilibrium has been established between the dissolved and undissolved solute.

PROBLEM

25. ANS:

Concentration (mol/L)	$HCN_{(aq)}$	+	$H_2O_{(l)}$	Û	$H_3O^+_{(aq)}$	+	$CN^{-(aq)}$
Initial	5.0×10^{-3}				0.0		0.0
Change	$-x$				x		x
Final	$(5.0 \times 10^{-3}) - x$				x		x

$$K_a = \frac{[H_3O^+][CN^-]}{[HCN]}$$

$$= \frac{x^2}{(5.0 \times 10^{-3}) - x}$$

$$= 4.9 \times 10^{-10}$$

Since x is very small, use an approximation.

$$\frac{x^2}{5.0 \times 10^{-3}} = 4.9 \times 10^{-10}$$

$$x^2 = 2.45 \times 10^{-12}$$

$$x = 1.6 \times 10^{-6}$$

The equilibrium concentrations of $H_3O^+_{(aq)}$ and $CN^-_{(aq)}$ are 1.6×10^{-6} mol/L. The equilibrium concentration of $HCN_{(aq)}$ is 5.0×10^{-3} mol/L.

26. ANS:

$$pH = -\log[H_3O^+_{(aq)}]$$

$$[H_3O^+] = 10^{-pH}$$

$$= 10^{-2.39}$$

$$= 4.1 \times 10^{-3} \text{ mol/L}$$

Concentration (mol/L)	$C_3H_6O_{3(aq)}$	+	$H_2O_{(l)}$	Û	$H_3O^+_{(aq)}$	+	$C_3H_5O_3^-{}_{(aq)}$
Initial	0.12				0.0		0.0
Change	-4.1×10^{-3}				4.1×10^{-3}		4.1×10^{-3}
Final	0.116				4.1×10^{-3}		4.1×10^{-3}

$$K_a = \frac{[H_3O^+][C_3H_5O_3^-]}{[C_3H_6O_3]}$$

$$= \frac{(4.1 \times 10^{-3})(4.1 \times 10^{-3})}{0.116}$$

$$= 1.45 \times 10^{-4}$$

Therefore, K_a is 1.45×10^{-4}.

30. ANS:

$$[Ca^{2+}_{(aq)}] = 0.0015 \text{ mol/L} \times \frac{V_{initial}}{V_{final}}$$

$$= 0.0015 \text{ mol/L} \times \frac{0.050 \text{ L}}{0.125 \text{ L}}$$

$$= 6.0 \times 10^{-4} \text{ mol/L}$$

$$[SO_4^{2-}{}_{(aq)}] = 0.010 \text{ mol/L} \times \frac{V_{initial}}{V_{final}}$$

$$= 0.010 \text{ mol/L} \times \frac{0.075 \text{ L}}{0.125 \text{ L}}$$

$$= 6.0 \times 10^{-3} \text{ mol/L}$$

$CaSO_{4(s)} \hat{U} Ca^{2+}{}_{(aq)} + SO_4^{2-}{}_{(aq)}$

$K_{sp} = [Ca^{2+}{}_{(aq)}][SO_4^{2-}{}_{(aq)}]$

$Q_{sp} = [Ca^{2+}{}_{(aq)}][SO_4^{2-}{}_{(aq)}]$

$= (6.0 \times 10^{-4})(6.0 \times 10^{-3})$

$= 3.6 \times 10^{-6}$

Since $Q_{sp} < K_{sp}$, no precipitate forms.

27.

	HA	$\leftrightarrow$	H^+	$+$	A^-
	0.024		0		0
	$-x$		$+x$		$+x$
	$0.024-x$		x		x
	$=0.024-6.0256\times10^{-4}$		6.0256×10^{-4}		6.0256×10^{-4}
	$=0.023397$				

$$pH = 3.22$$

$$[H^+] = 10^{-3.22} = 6.0256\times10^{-4} = x$$

$$K_a = \frac{[H^+][A^-]}{[HA]}$$

$$= \frac{(6.0256\times10^{-4})^2}{0.023397}$$

$$= 1.552\times10^{-5}$$

28.

	$A(OH)_3$	$\rightarrow$	Al^{+3}	$+$	$3OH^-$
	2.41×10^{-5}		2.41×10^{-5}		$3(2.41\times10^{-5})$
					$=7.23\times10^{-5}$

$$[OH] = 7.23\times10^{-5}$$

$$pOH = -\log(7.23\times10^{-5})$$

$$= 4.14$$

$$pH = 14 - 4.14$$

$$= 9.86$$

29.

HIO	$\leftrightarrow$	H^+	+	IO^-
0.455		0		0
$-x$		$+x$		$+x$
$0.455-x$		x		x
$0.455-0.0315$		$=0.0315$		$=0.0315$

$$pH = 1.502$$

$$x = [H^+] = 10^{-1.502}$$

$$= 0.0315$$

$$K_a = \frac{[H^+][IO^-]}{[HIO]}$$

$$= \frac{(.0315)^2}{0.4235}$$

$$= 2.34 \times 10^{-3}$$