KEY

ACIDS/BASES/SALTS
EQUILIBRIUM – ALL TYPES

Heat + $2\,BaO_2(s) \rightleftarrows 2\,BaO(s) + O_2(g)$

$\Delta H^\circ = 162\ kJ/mol_{rxn}$ endo

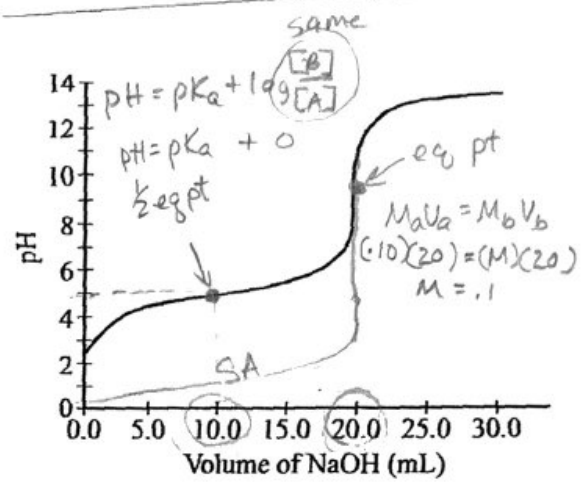
$K_c = [O_2]$

$K_p = P_{O_2}$

(s) (s)

4. A sealed rigid vessel contains $BaO_2(s)$ in equilibrium with $BaO(s)$ and $O_2(g)$ as represented by the equation above. Which of the following changes will increase the amount of $BaO_2(s)$ in the vessel?

(A) Removing a small amount of $O_2(g)$ shift Rt, ↓ BaO_2
(B) Removing a small amount of $BaO(s)$ no shift
(C) Adding He gas to the vessel no shift
(D) Lowering the temperature ↓Heat, shift Left, ↑ BaO_2



38. Data collected during the titration of a 20.0 mL sample of a 0.10 *M* solution of a monoprotic acid HA with a solution of NaOH of unknown concentration are plotted in the graph above. Based on the data, which of the following are the approximate pK_a of the acid and the molar concentration of the NaOH?

	pK_a	[NaOH]
(A)	4.7	0.050 *M*
(B)	4.7	0.10 *M*
(C)	9.3	0.050 *M*
(D)	9.3	0.10 *M*

pH = 5
pKa = 5

19. A solution containing HCl and the weak acid $HClO_2$ has a pH of 2.4. Enough KOH(*aq*) is added to the solution to increase the pH to 10.5. The amount of which of the following species increases as the KOH(*aq*) is added?

(A) $Cl^-(aq)$ $HCl \rightarrow H^+ + Cl^-$ mixed because 100% ionization
(B) $H^+(aq)$ $HClO_2 \rightleftharpoons H^+ + ClO_2^-$
(C) $ClO_2^-(aq)$ ↑$[OH^-]$, ↓H^+, shift Rt, ↑$[ClO_2^-]$
(D) $HClO_2(aq)$

1.5 M 1.0 M 2.5 M $Q = \frac{2.5}{(1.5)(1.0)} = 1.7$
1.5 mol 1.0 mol 2.5 mol

$PCl_3(g) + Cl_2(g) \rightleftarrows PCl_5(g)$ $K_c = 6.5$

to reach eq →

P/R

36. At a certain point in time, a 1.00 L rigid reaction vessel contains 1.5 mol of $PCl_3(g)$, 1.0 mol of $Cl_2(g)$, and 2.5 mol of $PCl_5(g)$. Which of the following describes how the measured pressure in the reaction vessel will change and why it will change that way as the reaction system approaches equilibrium at constant temperature?

(A) The pressure will increase because $Q < K_c$.
(B) The pressure will increase because $Q > K_c$.
(C) The pressure will decrease because $Q < K_c$.
(D) The pressure will decrease because $Q > K_c$.

11. When 200. mL of 2.0 *M* NaOH(*aq*) is added to 500. mL of 1.0 *M* HCl(*aq*), the pH of the resulting mixture is closest to

(A) 1.0
(B) 3.0
(C) 7.0
(D) 13.0

HCl + NaOH → NaCl + H_2O
500 mmol 400 mmol 0
−400 −400
100 0 +100
100

excess

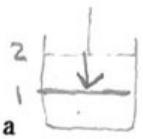
$\frac{100\ mmol}{700\ mL} = \frac{1}{7}\ M\ HCl$ ← strong acid

$-\log .1 = 1$

1.

↓V, ↑P of all gases, Shift Rt

$CO + 2H_2 \rightleftharpoons CH_3OH$



Questions 21-24 refer to the following information.

+Heat exo

$CO(g) + 2\,H_2(g) \rightleftarrows CH_3OH(g) \quad \Delta H < 0$ (−)

The synthesis of $CH_3OH(g)$ from $CO(g)$ and $H_2(g)$ is represented by the equation above. The value of K_c for the reaction at 483 K is 14.5. K = 14.5

21. Which of the following explains the effect on the equilibrium constant, K_c, when the temperature of the reaction system is increased to 650 K? shift Left

    P↓ R↑

    (A) K_c will increase because the activation energy of the forward reaction increases more than that of the reverse reaction.
    (B) K_c will increase because there are more reactant molecules than product molecules.
    (C) K_c will decrease because the reaction is exothermic.
    (D) K_c is constant and will not change.

22. A 1.0 mol sample of $CO(g)$ and a 1.0 mol sample of $H_2(g)$ are pumped into a rigid, previously evacuated 2.0 L reaction vessel at 483 K. Which of the following is true at equilibrium?

    (A) $[H_2] = 2[CO]$ ✗
    (B) $[H_2] < [CO]$ ✓
    (C) $[CO] = [CH_3OH] < [H_2]$ ✗ K>1
    (D) $[CO] = [CH_3OH] = [H_2]$ ✗

$CO + 2H_2 \rightleftharpoons CH_3OH$

1.0 1.0 0

−.1 −.2 +.1

.9 .8 .1

23. A mixture of $CO(g)$ and $H_2(g)$ is pumped into a previously evacuated 2.0 L reaction vessel. The total pressure of the reaction system is 1.2 atm at equilibrium. What will be the total pressure of the system if the volume of the reaction vessel is reduced to 1.0 L at constant temperature?

    (A) Less than 1.2 atm
    (B) Greater than 1.2 atm but less than 2.4 atm
    (C) 2.4 atm
    (D) Greater than 2.4 atm

24. Which of the following statements is true about bond energies in this reaction?

    (A) The energy absorbed as the bonds in the reactants are broken is greater than the energy released as the bonds in the product are formed. NO +
    (B) The energy released as the bonds in the reactants are broken is greater than the energy absorbed as the bonds in the product are formed.
    (C) The energy absorbed as the bonds in the reactants are broken is less than the energy released as the bonds in the product are formed. −
    (D) The energy released as the bonds in the reactants are broken is less than the energy absorbed as the bonds in the product are formed.

Buffer

25. A solution is prepared by adding 100 mL of 1.0 *M* $HC_2H_3O_2(aq)$ to 100 mL of 1.0 *M* $NaC_2H_3O_2(aq)$. The solution is stirred and its pH is measured to be 4.73. After 3 drops of 1.0 *M* HCl are added to the solution, the pH of the solution is measured and is still 4.73. Which of the following equations represents the chemical reaction that accounts for the fact that acid was added but there was no detectable change in pH?

    (A) $H_3O^+(aq) + OH^-(aq) \rightarrow 2\,H_2O(l)$
    (B) $H_3O^+(aq) + Cl^-(aq) \rightarrow HCl(g) + H_2O(l)$
    (C) $H_3O^+(aq) + C_2H_3O_2^-(aq) \rightarrow HC_2H_3O_2(aq) + H_2O(l)$
    (D) $H_3O^+(aq) + HC_2H_3O_2(aq) \rightarrow H_2C_2H_3O_2^+(aq) + H_2O(l)$

$HC_2H_3O_2$ Acid

$C_2H_3O_2^-$ Base

$C_2H_3O_2^- + H_3O^+ \rightarrow HC_2H_3O_2 + H_2O$

part of the buffer — from the HCl

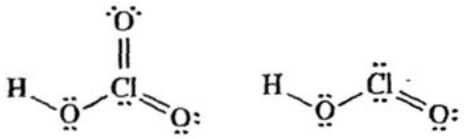
Acid Solution	Volume of NaOH Added (mL)
A	40
B	75
C	115
D	200

$M_aV_a = M_bV_b$
$(M)(100) = (.2)$
$(.2)(100)\ (.2)(100)$
$(.3)(100) = (.2)(150)$

41. To maximize the yield in a certain manufacturing process, a solution of a weak monoprotic acid that has a concentration between 0.20 *M* and 0.30 *M* is required. Four 100. mL samples of the acid at different concentrations are each titrated with a 0.20 *M* NaOH solution. The volume of NaOH needed to reach the end point for each sample is given in the table above. Which solution is the most suitable to maximize the yield?

(A) Solution A
(B) Solution B
(C) Solution C
(D) Solution D

$(M_a)(V_a) = (M_b)(V_b)$
$(M_a)(100) = (.20)(40)$ $M_a = .08$
$(M_a)(100) = (.20)(75)$ $M_a = .15$
$(M_a)(100) = (.20)(115)$ $M_a = .23$
$(M_a)(100) = (.20)(200)$ $M_a = .40$



38. The Lewis electron-dot diagrams of the $HClO_3$ molecule and the $HClO_2$ molecule are shown above at the left and right, respectively. Which of the following statements identifies the stronger acid and correctly identifies a factor that contributes to its being the stronger acid?

(A) $HClO_3(aq)$ is the stronger acid because its molecules experience stronger London dispersion forces. NO!
(B) $HClO_3(aq)$ is the stronger acid because the additional electronegative oxygen atom on the chlorine atom stabilizes the conjugate base. (weakens the bond between H and O)
(C) $HClO_2(aq)$ is the stronger acid because its molecules experience weaker London dispersion forces.
(D) $HClO_2(aq)$ is the stronger acid because the lone pairs of electrons on the chlorine atom stabilize the conjugate base.

$X(g) + 2\,Q(g) \rightleftarrows R(g) + Z(g)$ $K_c = 1.3 \times 10^5$ at 50°C

Prod. favored!

46. A 1.0 mol sample of X(*g*) and a 1.0 mol sample of Q(*g*) are introduced into an evacuated, rigid 10.0 L container and allowed to reach equilibrium at 50°C according to the equation above. At equilibrium, which of the following is true about the concentrations of the gases?

(A) $[R] = \frac{1}{2}[Q]$
(B) $[Q] = \frac{1}{2}[X]$
(C) $[R] = [Z] > [Q]$
(D) $[X] = [Q] = [R] = [Z]$

	X	+ 2Q	⇌ R	+ Z
	1.0	1.0	0	0
	−.1	−.2	+.1	+.1
	.9	.8	.1	.1

equal

SCB

$HX(aq) + Y^-(aq) \rightleftarrows HY(aq) + X^-(aq)$ $K_{eq} > 1$

45. A solution of a salt of a weak acid HY is added to a solution of another weak acid HX. Based on the information given above, which of the following species is the strongest base?

(A) $HX(aq)$ WA
(B) $Y^-(aq)$ SCB
(C) $HY(aq)$ WA
(D) $X^-(aq)$ SCB

$$2\,XY(g) \rightleftarrows X_2(g) + Y_2(g) \qquad K_p = 230$$

16. A certain gas, $XY(g)$, decomposes as represented by the equation above. A sample of each of the three gases is put in a previously evacuated container. The initial partial pressures of the gases are shown in the table below.

Gas	Initial Partial Pressure (atm)
XY	0.010
X_2	0.20
Y_2	2.0

$K = \frac{(P_{X_2})(P_{Y_2})}{(P_{XY})^2} = 230$

$Q = \frac{(.20)(2.0)}{(.010)^2} = \frac{.40}{.0001} = 4000$

$Q > K$

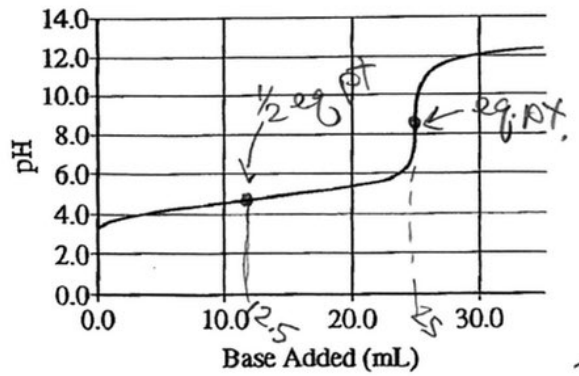
The temperature of the reaction mixture is held constant. In which direction will the reaction proceed?

(A) The reaction will form more products.
(B) The reaction will form more reactant.
(C) The mixture is at equilibrium, so there will be no change.
(D) It cannot be determined unless the volume of the container is known.

Questions 17-20 refer to the following information.

A 0.35 g sample of $Li(s)$ is placed in an Erlenmeyer flask containing 100 mL of water at 25°C. A balloon is placed over the mouth of the flask to collect the hydrogen gas that is generated.

After all of the $Li(s)$ has reacted with $H_2O(l)$, the solution in the flask is added to a clean, dry buret and used to titrate an aqueous solution of a monoprotic acid. The pH curve for this titration is shown in the diagram below.



17. Which of the following changes will most likely increase the rate of reaction between $Li(s)$ and water?

(A) Using 125 mL of water instead of 100 mL
(B) Using a 0.25 g sample of $Li(s)$ instead of a 0.35 g sample
(C) Using a 0.35 g sample of $Li(s)$ cut into small pieces
(D) Decreasing the water temperature before adding the $Li(s)$

18. What will be the effect on the amount of gas produced if the experiment is repeated using 0.35 g of $K(s)$ instead of 0.35 g of $Li(s)$?

(A) No gas will be produced when $K(s)$ is used.
(B) Some gas will be produced but less than the amount of gas produced with $Li(s)$.
(C) Equal quantities of gas will be produced with the two metals.
(D) More gas will be produced with $K(s)$ than with $Li(s)$.

$2Li(s) + 2H_2O(l) \rightarrow 2LiOH(aq) + H_2(g)$

19. On the basis of the pH curve, the pK_a value of the acid is closest to

(A) 4
(B) 5
(C) 8
(D) 12

20. Which of the following is the balanced net-ionic equation for the reaction between Li(*s*) and water?

(A) $2\,Li(s) + 2\,H^+(aq) + 2\,OH^-(aq) \rightarrow 2\,Li^+(aq) + 2\,OH^-(aq) + H_2(g)$
(B) $2\,Li(s) + 2\,H_2O(l) \rightarrow 2\,Li^+(aq) + 2\,OH^-(aq) + H_2(g)$
(C) $2\,Li(s) + 2\,H_2O(l) \rightarrow 2\,LiOH(s) + H_2(g)$
(D) $2\,Li(s) + 2\,H_2O(l) \rightarrow 2\,LiH(s) + H_2(g)$

$H_3PO_4 \rightleftarrows H^+ + H_2PO_4^-$ $\quad K_{a_1} = 7.2 \times 10^{-3}$
$H_2PO_4^- \rightleftarrows H^+ + HPO_4^{2-}$ $\quad K_{a_2} = 6.3 \times 10^{-8}$
$HPO_4^{2-} \rightleftarrows H^+ + PO_4^{3-}$ $\quad K_{a_3} = 4.5 \times 10^{-13}$

getting weaker

50 mmol

15. A solution is prepared by mixing 50 mL of 1 *M* NaH_2PO_4 with 50 mL of 1 *M* Na_2HPO_4. On the basis of the information above, which of the following species is present in the solution at the lowest concentration?

(A) Na^+
(B) HPO_4^{2-}
(C) $H_2PO_4^-$
(D) PO_4^{3-}

$H_2PO_4^- \rightleftharpoons HPO_4^{2-} + H^+$
$HPO_4^{2-} \rightleftharpoons PO_4^{3+} + H^+$

$Mg(OH)_2(s) \rightleftarrows Mg^{2+}(aq) + 2\,OH^-(aq)$ + Heat

13. The exothermic dissolution of $Mg(OH)_2(s)$ in water is represented by the equation above. The K_{sp} of $Mg(OH)_2$ is 1.8×10^{-11}. Which of the following changes will increase the solubility of $Mg(OH)_2$ in an aqueous solution?

$K_{sp} = [Mg^{2+}][OH^-]^2$

$1.8 \times 10^{-11} = (x)(2x)^2$

(A) Decreasing the pH add acid, ↓$[OH^-]$, shift R→
(B) Increasing the pH add OH^-, ↑$[OH^-]$, shift ←Left
(C) Adding NH_3 to the solution reacts w/ H_2O + produces hydroxide, shift ←Left
(D) Adding $Mg(NO_3)_2$ to the solution introduce a common ion, Mg^{2+} → will shift eq to the ←Left (Mg^{2+} is common ion.)

$$\text{heat} + CaCO_3(s) \rightleftarrows CaO(s) + CO_2(g)$$

$$\Delta H^\circ = 178 \text{ kJ/mol}_{rxn}$$

endo

$K_c = [CO_2]$

$K_p = P_{CO_2}$

40. The reaction system represented above is at equilibrium. Which of the following will decrease the amount of $CaO(s)$ in the system?

(A) Increasing the volume of the reaction vessel at constant temperature ↑V, ↓P, shift R+

(B) Lowering the temperature of the system ↓T, shift left

(C) Removing some $CO_2(g)$ at constant temperature shift R+

(D) Removing some $CaCO_3(s)$ at constant temperature no effect

	K_a	pK_a
$HC_3H_5O_3(aq)$	8.3×10^{-4}	3-4
$CH_3NH_3^+(aq)$	2.3×10^{-11}	10-11

37. The acid-dissociation constants of $HC_3H_5O_3(aq)$ and $CH_3NH_3^+(aq)$ are given in the table above. Which of the following mixtures is a buffer with a pH of approximately 3 ?

$pH = pK_a + \log \frac{B}{A}$ (zero)

What will make these the same

(A) A mixture of 100. mL of 0.1 *M* CH_3NH_3Cl and 50. mL of 0.1 *M* NaOH

(B) A mixture of 100. mL of 0.1 *M* $HC_3H_5O_3$ and 50. mL of 0.1 *M* NaOH

(C) A mixture of 100. mL of 0.1 *M* $NaC_3H_5O_3$ and 100. mL of 0.1 *M* NaOH 2 bases

(D) A mixture of 100. mL of 0.1 *M* CH_3NH_3Cl and 100. mL of 0.1 *M* CH_3NH_2

$$HF(aq) + H_2O(l) \rightleftarrows H_3O^+(aq) + F^-(aq)$$

33. The dissociation of the weak acid HF in water is represented by the equation above. Adding a 1.0 mL sample of which of the following would increase the percent ionization of HF(*aq*) in 10 mL of a solution of 1.0 *M* HF ? shift R+

(A) 1.0 *M* KF ← common ion F^-

(B) 1.0 *M* H_2SO_4 ← common ion H_3O^+

(C) 10.0 *M* HF is same no matter how much is used !!

(D) Distilled water

Solution	Acid	K_a
1	CH_3CO_2H	1.75×10^{-5} ← weaker acid
2	CF_3CO_2H	1.0×10^{0} ← stronger acid

22. Acid-dissociation constants of two acids are listed in the table above. A 20. mL sample of a 0.10 *M* solution of each acid is titrated to the equivalence point with 20. mL of 0.10 *M* NaOH. Which of the following is a true statement about the pH of the solutions at the equivalence point?

(A) Solution 1 has a higher pH at the equivalence point because CH_3CO_2H is the stronger acid.

(B) Solution 1 has a higher pH at the equivalence point because CH_3CO_2H has the stronger conjugate base. → greater extent of hydrolysis rxn

(C) Solution 1 has a lower pH at the equivalence point because CH_3CO_2H is the stronger acid.

(D) Solution 1 has a lower pH at the equivalence point because CH_3CO_2H has the stronger conjugate base.

30. Which of the following accounts for the observation that the pH of pure water at 37°C is 6.8 ? $\text{Heat} + H_2O \rightleftarrows H^+ + OH^-$

(A) At 37°C water is naturally acidic.

(B) At 37°C the autoionization constant for water, K_w, is larger than it is at 25°C.

(C) At 37°C water has a lower density than it does at 25°C; therefore, $[H^+]$ is greater.

(D) At 37°C water ionizes to a lesser extent than it does at 25°C.

10. An acetate buffer solution is prepared by combining 50. mL of 0.20 *M* acetic acid, $HC_2H_3O_2(aq)$, and 50. mL of 0.20 *M* sodium acetate, $NaC_2H_3O_2(aq)$. A 5.0 mL sample of 0.10 *M* NaOH(*aq*) is added to the buffer solution. Which of the following is a correct pairing of the acetate species present in greater concentration and of the pH of the solution after the NaOH(*aq*) is added? (The pK_a of acetic acid is 4.7.)

	Acetate Species	pH
(A)	$HC_2H_3O_2$	< 4.7
(B)	$HC_2H_3O_2$	> 4.7
(C)	$C_2H_3O_2^-$	< 4.7
(D)	$C_2H_3O_2^-$	> 4.7

$HC_2H_3O_2 + OH^- \Rightarrow C_2H_3O_2^- + H_2O$

	10 mmol	.5 mmol	10 mmol
	-.5	-.5	+.5
	9.5	0	10.5