

This exam should have 25 questions. The point values are given with each question. Bubble in your answer choices on the bubbleseet provided. Your score is based on what you bubble on the bubblesheet and not what is circled on the exam. Below are some constants you might want to use.

Acid	$K_a$	Base	$K_b$
acetic acid	$1.8 \times 10^{-5}$	ammonia	$1.8 \times 10^{-5}$
benzoic acid	$6.4 \times 10^{-5}$	hydrazine	$1.7 \times 10^{-6}$
chlorous acid	$1.2 \times 10^{-2}$	hydroxylamine	$9.1 \times 10^{-9}$
formic acid	$1.8 \times 10^{-4}$	pyridine	$1.7 \times 10^{-9}$
hypochlorous acid	$3.5 \times 10^{-8}$	ethylenediamine	1) $8.5 \times 10^{-5}$ 2) $7.0 \times 10^{-8}$
malonic acid	1) $1.4 \times 10^{-3}$ 2) $2.0 \times 10^{-6}$		
oxalic acid	1) $5.6 \times 10^{-2}$ 2) $5.4 \times 10^{-5}$		

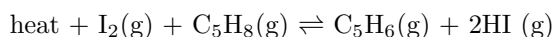
- 1 The following reaction is at equilibrium at 250 K: (4 points)



You increase the temperature to 500 K. How will the equilibrium concentration of  $\text{I}_2(\text{g})$  change?

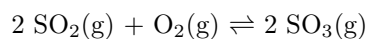
- A. It will increase.  
 B. It will decrease.  
 C. It will not change.

**Explanation:** For this endothermic reaction, you can consider the reaction to be:



At increased temperatures, the equilibrium constant increases and our reaction will shift to make more products.

- 2 At equilibrium at a certain temperature, you find concentrations of 0.600 M  $\text{SO}_2(\text{g})$ , 0.300 M  $\text{O}_2(\text{g})$ , and 3.28 M  $\text{SO}_3(\text{g})$ . Given the reaction: (4 points)



Calculate  $K_c$  at this temperature.

- A. 99.6  
 B. 18.2  
 C.  $1.00 \times 10^{-2}$   
 D. 54.6  
 E.  $2.36 \times 10^{-4}$

**Explanation:**  $K_c = \frac{[\text{SO}_3]^2}{[\text{SO}_2]^2[\text{O}_2]} = \frac{(3.28)^2}{(.6)^2(.3)}$

3 Consider the reaction:  $\text{PCl}_3(\text{g}) + \text{Cl}_2(\text{g}) \rightleftharpoons \text{PCl}_5(\text{g})$  (4 points)

Calculate  $\Delta G_{\text{rxn}}$  for this reaction at  $230^\circ\text{C}$  knowing that  $K_p$  is equal to 50 at this temperature.

- ✓ A. -16.3 kJ/mol rxn
- B. -7.44 kJ/mol rxn
- C. -0.0733 kJ/mol rxn
- D. +7.44 kJ/mol rxn
- E. + 16.3 kJ/mol rxn

**Explanation:**  $\Delta G_{\text{rxn}} = -RT \ln K$ , where  $R$  is the gas constant 8.314 J/mol K;  $T$  is the absolute temperature and  $K$  is the thermodynamic equilibrium constant. Plugging given values into this equation and converting to kJ will give the correct answer - 16.3 kJ/mol rxn

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4 Which of the following weak bases will have the strongest conjugate acid? (4 points)

- ✓ A.  $(\text{CH}_3)_3\text{N}$ ;  $K_b = 6.5 \times 10^{-5}$
- B.  $\text{CH}_3\text{NH}_2$ ;  $K_b = 3.6 \times 10^{-4}$
- C.  $(\text{CH}_3)_2\text{NH}$ ;  $K_b = 5.4 \times 10^{-4}$
- D.  $\text{C}_2\text{H}_5\text{NH}_2$ ;  $K_b = 6.5 \times 10^{-4}$

**Explanation:** For every conjugate acid base pair,  $K_a \times K_b = K_w$ . Therefore, the weakest base will have the strongest conjugate acid partner. The larger the value of the equilibrium constant the greater the extent of ionization.

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5 It is possible to make a solution of a weak acid that has a lower pH than a solution of a strong acid. (4 points)

- ✓ A. This statement is true because a very high concentration of a weak acid can yield a more acidic solution than an very dilute solution of a strong acid.
- B. This statement is false because as long as the concentration of the strong acid is the same as the concentration of the weak acid, the pH of the solutions will be identical.
- C. This statement is true because a very low concentration of a weak acid will have the same pH as a moderately high concentration of a strong acid.
- D. This statement is false because a strong acid will always have a lower pH than a weak acid regardless of the concentration of the acid.

**Explanation:** The pH is dependent on the extent of ionization and the concentration of the acid. It is possible to have a very dilute solution of a strong acid that has a higher pH than a very concentrated solution of a weak acid.

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6 Determine the pH of a 0.0146 M solution of HBr. (4 points)

- A. 1.84  
B. impossible,  $K_a$  was not given  
C. 12.2  
D. 3.67  
E. 4.23

**Explanation:** HBr is a strong acid. Strong acids ionize 100% in solution. Therefore, the concentration of the hydronium ion is the same as the stated concentration of the strong acid.  $\text{pH} = -\log(0.0146)$

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7 Determine the pH of a 0.42 M solution of hypochlorous acid, HClO. (4 points)

- A. 4.95  
B. 0.38  
 C. 3.92  
D. 2.88  
E. 5.61

**Explanation:**  $K_a = 3.5 \times 10^{-8}$ .  $[\text{H}^+] \approx \sqrt{K_a(.42)}$ . This gives you  $[\text{H}^+] = 1.21 \times 10^{-4}$  M. The  $\text{pH} = -\log[\text{H}^+] = 3.92$

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8 Determine the pH of a 0.19 M solution of hydrazine,  $\text{NH}_2\text{NH}_2$ . (4 points)

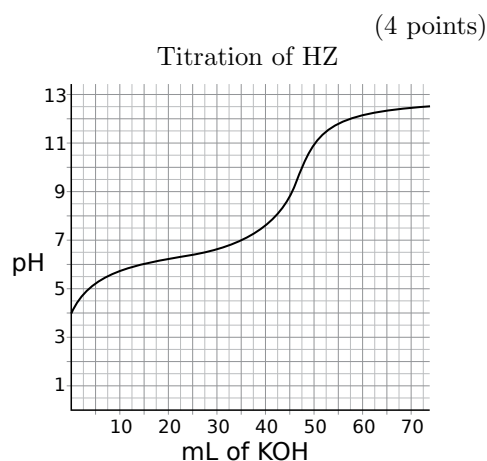
- A. 10.75  
B. 9.66  
C. 4.34  
D. 3.25  
E. 13.28

**Explanation:** Hydrazine is a weak base.  $K_b = 1.7 \times 10^{-6}$ .  $[\text{OH}^-] \approx \sqrt{K_b(.19)}$ . This gives you  $[\text{OH}^-] = 5.68 \times 10^{-4}$  M. The  $\text{pOH} = -\log[\text{OH}^-] = 3.25$  The  $\text{pH} = 14 - 3.25 = 10.75$ .

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- 9 A sample of 25.0 mL of a weak acid (HZ) was titrated with a 0.038 M solution of KOH. The resulting pH curve for this titration is shown in the figure to the right. Using this data, determine the original concentration of the weak acid HZ.

- A. 0.055 M  
 B. 0.060 M  
 C. 0.065 M  
 ✓ D. 0.070 M  
 E. 0.075 M  
 F. 0.080 M  
 G. 0.085 M



**Explanation:** Analysis of the pH curve reveals that the endpoint of the titration corresponds to a volume of approximately 46 mL of the KOH solution.  $46\text{mL}(0.038\text{M}) = 1.748 \text{ mmol of OH}^-$ . There is the same number of mmol of the weak acid HZ. Divide mmol by volume to get concentration of the HZ:  $1.748/25 = 0.70 \text{ M HZ}$ .

- 10 Please refer to the titration curve shown in the previous problem.

(4 points)

Analyze the titration curve and determine the value of  $K_a$  for the weak acid HZ.

- A.  $1.0 \times 10^{-6}$   
 ✓ B.  $5.0 \times 10^{-7}$   
 C.  $2.5 \times 10^{-7}$   
 D.  $1.2 \times 10^{-8}$   
 E.  $4.5 \times 10^{-10}$   
 F.  $3.1 \times 10^{-9}$   
 G.  $8.5 \times 10^{-6}$

**Explanation:** The endpoint of the titration is about 46 mL. Half of that value is 23 mL. The pH from the curve at 23 mL is about 6.3 which will be the same as the  $\text{p}K_a$  for the weak acid. So that  $K_a = 10^{-6.3} = 5.0 \times 10^{-7}$ .

- 11 A 0.019 M solution of 2-chloropropionic acid is 21.3% ionized at 25°C. What is the ionization constant ( $K_a$ ) for this organic weak acid? (4 points)
- A.  $2.1 \times 10^{-1}$
  - B.  $3.5 \times 10^{-2}$
  - ✓ C.  $1.1 \times 10^{-3}$
  - D.  $6.3 \times 10^{-2}$
  - E.  $4.2 \times 10^{-3}$
  - F.  $2.1 \times 10^{-4}$
  - G.  $8.6 \times 10^{-4}$

**Explanation:** 21.3% of .019 is 0.00405 M which is the amount ionized (the H+ and the A-). This leaves  $0.019 - 0.00405 = 0.0150$  M of the unionized acid (HA) in solution. Now plug in those numbers in the mass action expression for  $K_a$ :

$$K_a = [H^+][A^-]/[HA] = (0.00405)^2/0.015 = 1.1 \times 10^{-3}$$

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- 12 What is the pOH of a 0.0048 M solution of chloric acid,  $\text{HClO}_3$ ? (4 points)
- A. 1.36
  - B. 3.23
  - C. 2.32
  - D. 12.74
  - ✓ E. 11.68
  - F. 10.77

**Explanation:**

$$[OH^-] = K_w/[H^+] = 1.0 \times 10^{-14}/0.0048 = 2.0833 \times 10^{-12}$$

Take the -log for pOH and get 11.68.

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- 13 75 mL of 0.015 M  $\text{HNO}_3$  is added to 100 mL of 0.012 M KOH. What is the final concentration of  $\text{H}^+$  (or  $\text{H}_3\text{O}^+$  if you prefer)? (4 points)
- ✓ A.  $2.33 \times 10^{-11}$  M
  - B.  $1.71 \times 10^{-5}$  M
  - C.  $1.33 \times 10^{-11}$  M
  - D.  $7.5 \times 10^{-4}$  M
  - E.  $7.5 \times 10^{-11}$  M

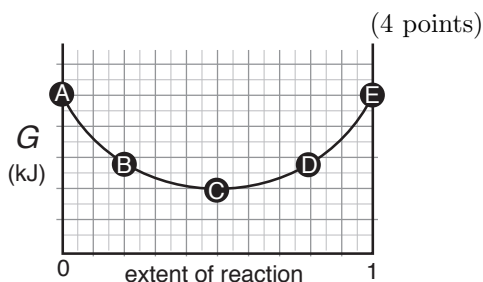
**Explanation:**  $75(0.015) = 1.125$  mmol  $\text{H}^+$ .  $100(.012) = 1.200$  mmol  $\text{OH}^-$ . Limiting reactant is the acid and  $1.2 - 1.125 = 0.075$  mmol of  $\text{OH}^-$  left over in 175 mL of solution which means the concentration of  $\text{OH}^-$  is  $4.29 \times 10^{-4}$  M. This makes the  $\text{H}^+$  concentration equal to  $2.33 \times 10^{-11}$  M.

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17 For this reaction,  $\Delta G^\circ$  is \_\_\_\_\_ and the equilibrium mixture is represented by spot \_\_\_\_\_

- ✓ A. zero ; C  
 B. negative ; D  
 C. negative ; B  
 D. zero ; A  
 E. zero ; E



**Explanation:** The equilibrium position is the lowest point on the diagram which is spot C. The start and finish free energies are identical which means that  $\Delta G^\circ$  is zero.

18 Write the equilibrium constant expression for fluoroacetic acid,  $\text{CH}_2\text{FCOOH}$ , ionizing in water.

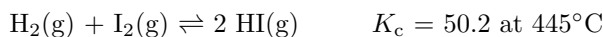
(4 points)

- A.  $\frac{[\text{CH}_2\text{FCOOH}][\text{H}_2\text{O}]}{[\text{CH}_2\text{FCOO}^-][\text{H}_3\text{O}^+]}$   
 B.  $\frac{[\text{CH}_2\text{FCOO}^-][\text{H}_3\text{O}^+]}{[\text{CH}_2\text{FCOOH}][\text{H}_2\text{O}]}$   
 C.  $\frac{[\text{CH}_2\text{FCOOH}]}{[\text{CF}^-\text{COO}^-]^3[\text{H}_3\text{O}^+]}$   
 ✓ D.  $\frac{[\text{CH}_2\text{FCOO}^-][\text{H}_3\text{O}^+]}{[\text{CH}_2\text{FCOOH}]}$   
 E.  $\frac{[\text{CF}^-\text{COO}^-]^3[\text{H}_3\text{O}^+]}{[\text{CH}_2\text{FCOOH}]}$

**Explanation:** Fluoroacetic acid donates one proton to water, producing hydronium ion and  $\text{CH}_2\text{FCOO}^-$

19 Consider the following reaction where you introduce 0.1 mol  $\text{H}_2$ , 0.1 mol  $\text{I}_2$ , and 0.1 mol  $\text{HI}$  into a 1 L flask at  $445^\circ\text{C}$ .

(4 points)

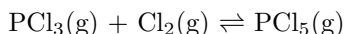


In what direction will this reaction proceed?

- A. to the left, producing more reactants  
 ✓ B. to the right, producing more products  
 C. the system is already at equilibrium

**Explanation:**  $Q = 1$ , which is less than  $K_c$ . The reaction must proceed to the right to form an equilibrium mixture.

20 The following reaction is at equilibrium in a 1 L vessel: (4 points)



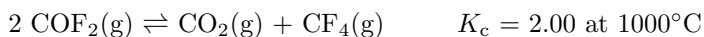
You compress the gas mixture to 0.5 L total volume. How will the reaction equilibrium shift in response to this volume change?

- A. It will shift to the left, making more reactants.
- ✓ B. It will shift to the right, making more products.
- C. Equilibrium will not shift.

**Explanation:** The volume change will cause an increase in the partial pressures of each component of the mixture. Consider the equilibrium expression,  $K_p = P_{\text{PCl}_5} / P_{\text{PCl}_3} P_{\text{Cl}_2}$ . Calculating  $Q$  right after the shift, we can see that the increase in partial pressures will have more of an effect on the denominator of our expression, making  $Q$  less than  $K$  and meaning more products need to be made to bring the system to equilibrium. In a situation where the pressure is increasing, the system will shift towards the side of the equation with the fewest moles of gas particles.

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21 Consider this reaction: (4 points)



You place 0.3 mol  $\text{COF}_2(\text{g})$ , 0.2 mol  $\text{CO}_2(\text{g})$ , and 0.2 mol  $\text{CF}_4(\text{g})$  in a 1 L vessel. What is the concentration of  $\text{COF}_2(\text{g})$  once equilibrium is established?

- A. 0.38 M
- B. 0.3 M
- C. 0.24 M
- ✓ D. 0.18 M
- E. 0.32 M
- F. 0.059 M

**Explanation:**  $Q < K_c$  so reaction will proceed towards products. You can use your RICE table to find  $K_c = (.2 + x)^2 / (.3 - 2x)^2$ .

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- 22 What is the pH of a 0.012 M solution of malonic acid (HOOCCH<sub>2</sub>COOH)? (4 points)
- A. 0.92
  - B. 1.89
  - C. 2.39
  - ✓ D. 2.46
  - E. 2.55
  - F. 3.11
  - G. 2.19

**Explanation:** Only the first proton ( $K_{a1}$ ) matters. After  $x$  dissociates, and using the RICE table you get:

$$K_{a1} = \frac{x^2}{0.012 - x}$$

You have to use the quadratic formula to solve for  $x$ . After doing so you get  $x = 3.46 \times 10^{-3}$  M for H<sup>+</sup>. This gives a pH of 2.46

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- 23 Which of the following will make a buffer solution? (4 points)
- ✓ A. 100 mL of 0.1M HCl and 100 mL of 0.2M CH<sub>3</sub>NH<sub>2</sub>
  - B. 100 mL of 0.2M HCl and 100 mL of 0.1M NaOH
  - C. 100 mL of 0.2M KOH and 100 mL of 0.2M HCOOH
  - D. 50 mL of 0.2M HCl and 100 mL 0.1M NH<sub>3</sub>
  - E. 200 mL of 0.1M NaOH and 100 mL of 0.1M HF

**Explanation:** To make a buffer solution you need to have substantial concentrations of both the acid and base forms of a conjugate pair. This can be most easily produced by neutralizing half of the concentration of a weak acid (or base) with strong base (or acid). In this case 100mL of 0.1 HCl will neutralize 0.01 moles of base. 100mL of a 0.2M solution of CH<sub>3</sub>NH<sub>2</sub> contains 0.02 moles of base. Neutralizing half of it you will end up with a buffer.

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- 24 You mix 100mL of a 0.1 M solution of benzoic acid with 50mL of 0.2M solution of potassium hydroxide. What is the pH of the resulting solution? (4 points)
- ✓ A. 8.51
  - B. 5.49
  - C. 5.40
  - D. 8.60
  - E. 2.60
  - F. 11.40

**Explanation:** In the solutions you have 0.01 moles of benzoic acid (0.1M)(0.1L) and 0.01 moles of OH<sup>-</sup> in 150 mL of solution. These two react to give 0.01 moles of the benzoate ion which is the conjugate base of benzoic acid. For benzoic acid the  $K_a = 6.4 \times 10^{-5}$ . Therefore for the benzoate ion  $K_b = (K_w)/(K_a) = 1.56 \times 10^{-10}$ . Solving the equilibrium yields  $[\text{OH}^-] = 3.23 \times 10^{-6}$ . This give  $[\text{H}_3\text{O}^+] = 3.10 \times 10^{-9}$ . pH = 8.51.

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- 25 Initially you have a 100 mL of a solution that has a formic acid concentration of 0.1M and a formate ion concentration of 0.1 M. What is the approximate pH of this solution after you add 50 mL of 0.1M HCl? (4 points)
- A. 4.22
  - ✓ B. 3.26
  - C. 3.74
  - D. 10.26
  - E. 10.74
  - F. 3.44
  - G. 4.04

**Explanation:** The solution begins with  $(0.1\text{M})(0.1\text{L}) = 0.01$  moles of formic acid and  $(0.1\text{L})(0.1\text{M}) = 0.01$  moles of the formate ion. If you add  $(0.05\text{L})(0.1\text{M}) = .005$  moles of  $\text{H}_3\text{O}^+$  to the solution the strong acid will react with the formate ion to form more formic acid. You will be left with 0.015 moles of formic acid and 0.005 moles of the formate ion. Therefore the  $pH = pK_a + \log\left[\frac{[A^-]}{[HA]}\right] = 3.74 + \log\left(\frac{.005}{0.015}\right) = 3.74 - 0.477 = 3.26$

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Remember to bubble in ALL your answers BEFORE time is called. Sign your bubblesheet AND your exam. Then turn in BOTH your exam copy and you bubblesheet.