

Each question is worth 5 points, unless otherwise indicated.

1. The pH of a 0.150 M solution of formic acid, HCOOH is
(K_a (formic acid) = 1.8×10^{-4}).

(A) 0.82 (C) 3.74 (E) 5.38
(B) 2.28 (D) 4.57

	$\text{HCOOH} + \text{H}_2\text{O} \rightleftharpoons \text{H}_3\text{O}^+ + \text{COOH}^-$			$K_a = 1.8 \times 10^{-4}$
Initial	0.150	0	0	
Change	-x	x	x	
Equilibrium	0.150-x	x	x	

So, $K_a = [\text{H}_3\text{O}^+][\text{COOH}^-]/[\text{HCOOH}] = (x)(x)/(0.150-x) = 1.8 \times 10^{-4}$

Assume x is small, so $0.15-x = 0.15$, then

$$(x^2)/0.15 = 1.8 \times 10^{-4}$$

$$x^2 = 2.7 \times 10^{-5}$$

$$x = [\text{H}_3\text{O}^+] = 5.2 \times 10^{-3} \text{ (and note that } x \text{ is much less than } 0.15)$$

$$\text{pH} = -\log [\text{H}_3\text{O}^+] = 2.28$$

2. The pH of a 0.05 M solution of nitric acid, HNO₃ is

(A) 0.05 (C) 0.70 (E) 2.00
(B) 0.10 (D) 1.30

HNO₃ is a strong acid, so it ionizes completely to form $\text{H}^+ + \text{NO}_3^-$. The H^+ combines with water to form H_3O^+ . So, the H_3O^+ concentration is 0.05 M

$$\text{pH} = -\log[\text{H}_3\text{O}^+] = -\log(0.05) = 1.30$$

3. An aqueous solution has a pH of 4.62. The $[\text{OH}^-]$ in the solution is

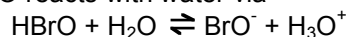
(A) 2.2×10^{-1} (C) 1.0×10^{-7} (E) 4.2×10^{-10}
(B) 2.4×10^{-5} (D) 8.3×10^{-8}

$\text{pH} = -\log[\text{H}_3\text{O}^+]$, so

$$[\text{H}_3\text{O}^+] = 10^{-\text{pH}} = 10^{-4.62} = 2.40 \times 10^{-5}$$

$$[\text{OH}^-] = 10^{-14}/[\text{H}_3\text{O}^+] = 10^{-14}/(2.40 \times 10^{-5}) = 4.16 \times 10^{-10}$$

4. HBrO reacts with water via



In this acid-base reaction, _____ and _____ act as Bronsted acids; while _____ and _____ are bases:

(A) HBrO, H₂O; BrO⁻, H₃O⁺
(B) HBrO, BrO⁻; H₂O, H₃O⁺
(C) HBrO, H₃O⁺; H₂O, BrO⁻
(D) H₂O, H₃O⁺; HBrO, BrO⁻
(E) BrO⁻, H₃O⁺; HBrO, H₂O

HBrO is an acid, it donates a proton to H₂O (base), producing BrO⁻ (conjugate base) and H₃O⁺ (acid)

5. Calculate the $[\text{CH}_3\text{COO}^-]/[\text{CH}_3\text{COOH}]$ ratio necessary to give a buffer with a pH of 5.00.

K_a for CH_3COOH (acetic acid) is 1.8×10^{-5}

(A) 1.00 (B) 1.07 (C) 0.55 (D) 0.26 (E) 1.82

$K_a = 1.8 \times 10^{-5}$, so $pK_a = -\log(K_a) = 4.74$

$pH = pK_a + \log([\text{conjugate base}]/[\text{acid}])$

$5.00 = 4.74 + \log([\text{conjugate base}]/[\text{acid}])$

$\log([\text{conjugate base}]/[\text{acid}]) = 0.26$

$[\text{conjugate base}]/[\text{acid}] = 10^{0.26} = 1.82$

(We did this as an example in class)

Questions 6 and 7 refer to a solution made by dissolving 0.020 mol of hydrazoic acid (HN_3) and 0.030 moles of sodium azide (NaN_3) in enough water to make 1.00 L of solution. pK_a for HN_3 is 4.72.

6. What is the approximate pH of this solution?

(A) 4.18 (C) 4.54 (E) 4.90
(B) 4.30 (D) 4.72

$pH = pK_a + \log([\text{conjugate base}]/[\text{acid}])$

$pH = 4.72 + \log(0.030/0.020)$

$pH = 4.72 + 0.18 = 4.90$

7. What is the approximate pH after the addition of 0.010 liters of 1M HCl to the solution?

(A) 4.18 (C) 4.54 (E) 2.00
(B) 4.30 (D) 4.72

Start with 0.020 moles hydrazoic acid (HN_3) and 0.030 moles azide (N_3^-) (Initial)

The 0.010 moles of HCl ionize completely to Cl^- and H^+ , which combines with water to form H_3O^+ , then H_3O^+ reacts with the base: (Change)

$\text{H}_3\text{O}^+ + \text{N}_3^- \rightarrow \text{HN}_3 + \text{H}_2\text{O}$

	HN_3	N_3^-
Initial	0.020 moles	0.030 moles
Change	+0.010 moles	-0.010 moles
Final	0.030 moles	0.020 moles

Concentrations: $[\text{HN}_3] = 0.03 \text{ moles}/1.01\text{L} = 0.0297 \text{ M}$

$[\text{N}_3^-] = 0.020 \text{ moles}/1.01 \text{ L} = 0.0198 \text{ M}$

$pH = pK_a + \log([\text{conjugate base}]/[\text{acid}])$

$pH = 4.72 + \log(0.0198/0.0297)$

$pH = 4.72 - 0.18 = 4.54$

8. The solubility of calcium fluoride is 0.018 grams per liter of water and the molecular weight of CaF_2 is 78.0 g/mol. The solubility product constant (K_{sp}) for CaF_2 is _____.

(A) 4.9×10^{-11} (C) 5.3×10^{-8} (E) 2.3×10^{-5}
(B) 5.8×10^{-9} (D) 5.8×10^{-6}

Concentrations:

$0.018 \text{ grams/L} \times 1 \text{ mol/78.0 grams} = 2.31 \times 10^{-4} \text{ M CaF}_2$, which dissolves to form $2.31 \times 10^{-4} \text{ M Ca}^{2+}$ and $2 \times 2.31 \times 10^{-4} = 4.62 \times 10^{-4} \text{ M F}^-$

$$K_{sp} = [\text{Ca}^{2+}][\text{F}^-]^2 = (2.31 \times 10^{-4}) (4.62 \times 10^{-4})^2 = 4.9 \times 10^{-11}$$

9. What is the $[Ca^{2+}]$ in a saturated $CaCO_3$ solution?

$$K_{sp} (CaCO_3) = 8.7 \times 10^{-9}$$

- (A) $2.1 \times 10^{-3} M$ (D) $8.7 \times 10^{-9} M$
 (B) $9.3 \times 10^{-5} M$ (E) $4.4 \times 10^{-9} M$
 (C) $6.2 \times 10^{-7} M$



Initial 0 0

Change x x

Equilibrium x x

$$K_{sp} = [Ca^{2+}][CO_3^{2-}]^2 = (x)(x) = 8.7 \times 10^{-9}$$

$$x^2 = 8.7 \times 10^{-9}$$

$$x = [Ca^{2+}] = 9.33 \times 10^{-5} M$$

10. The molar solubility of gold chloride ($AuCl_3$) in a 0.030 M NaCl solution is _____ M.

$$\text{For } AuCl_3 \quad K_{sp} = 3.2 \times 10^{-25}$$

Note: K_{sp} is so small that little of the gold chloride dissolves

- (A) 3.2×10^{-25} (C) 1.2×10^{-20} (E) 3.3×10^{-7}
 (B) 1.1×10^{-23} (D) 5.7×10^{-13}



Initial 0 0.030

Change x x

Equilibrium x 0.030+x

$$K_{sp} = [Au^{+}][Cl^{-}]^3 = (x)(0.030+x)^3 = 3.2 \times 10^{-25}$$

Can assume that x is much smaller than 0.030, so $0.030 + x$ is approximately 0.030

$$x(0.030)^3 = 3.2 \times 10^{-25}$$

$$x(2.7 \times 10^{-5}) = 3.2 \times 10^{-25}$$

$$x = \text{number of moles of } AuCl_3 \text{ that dissolve} = 1.19 \times 10^{-20} M$$

11. If a solution of Na_2SO_4 is added slowly to an aqueous solution which is 0.010 M in Ba^{2+} and 0.50 M in Sr^{2+} , which salt precipitates first, and at what concentration of SO_4^{2-} ? Assume no volume change.

$$BaSO_4 \quad K_{sp} = 1.1 \times 10^{-10} ; SrSO_4 \quad K_{sp} = 2.8 \times 10^{-7}$$

$$(A) BaSO_4, \text{ at } [SO_4^{2-}] = 1.1 \times 10^{-8} M$$

$$(B) BaSO_4, \text{ at } [SO_4^{2-}] = 5.6 \times 10^{-7} M$$

$$(C) SrSO_4, \text{ at } [SO_4^{2-}] = 2.2 \times 10^{-10} M$$

$$(D) SrSO_4, \text{ at } [SO_4^{2-}] = 1.1 \times 10^{-8} M$$

$$(E) SrSO_4, \text{ at } [SO_4^{2-}] = 5.6 \times 10^{-7} M$$

Minimum $[SO_4^{2-}]$ to start precipitation of $BaSO_4$ is when

$$[Ba^{2+}][SO_4^{2-}] = 1.1 \times 10^{-10}$$

$$(0.01 M)(x) = 1.1 \times 10^{-10}$$

$$x = 1.1 \times 10^{-8} M$$

Minimum $[SO_4^{2-}]$ to start precipitation of $SrSO_4$ is when

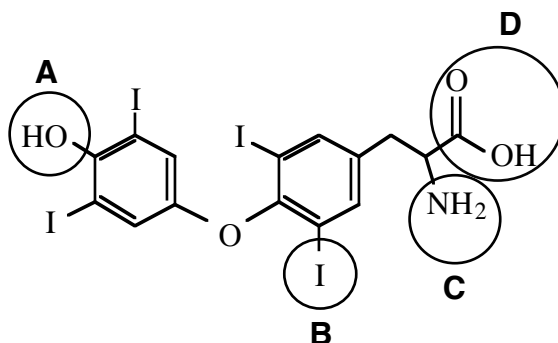
$$[Sr^{2+}][SO_4^{2-}] = 2.8 \times 10^{-7}$$

$$(0.50 M)(x) = 2.8 \times 10^{-7}$$

$$x = 5.6 \times 10^{-7} M$$

3 pts credit for (E)

12. Thyroxine (shown below) is a metabolism regulator produced in the thyroid gland. It is a complex molecule with many functional groups.



Which of the groups circled is the most basic ?

- (A) A (B) B (C) C (D) D

Group A is an alcohol (not acidic or basic), B is not acidic or basic, D is a carboxylic acid, C is an amine, which is basic.

Questions 13-16 are worth 2 points each

For the following compounds, state whether a 0.1 M solution will be

- (A) acidic
(B) basic
(C) pH neutral

13. NaF

(B) NaF is formed by reaction of NaOH (strong base) with HF (weak acid), so it's a basic salt

14. KOH

(B) KOH is a strong base

15. NH_4Cl

(A) NH_4Cl is formed by reaction of NH_3 (weak base) and HCl (strong acid), so it's an acidic salt

16. NaNO_3

(C) NaNO_3 is formed by reaction of NaOH (strong base) with HNO_3 (strong acid), so it's pH neutral

17. A chemist dissolves 5.60 grams of MgCl_2 (Molec. wt. = 95.2 g/mol) in 300 grams of water (Molec. wt. = 18.0 g/mol) to give a solution with a volume of 320 mL.

What is the molality of MgCl_2 in the solution?

- (A) 0.0187 (B) 0.0175 (C) 0.0163 (D) 0.184 (E) 0.196

molality = moles solute/kg of solvent

moles MgCl_2 (solute) = 5.60 g/(95.2 g/mol) = 0.0588 moles

molality = 0.0588 moles MgCl_2 /0.300 kg water = 0.196 m

(Note: you were asked to calculate the molality, not the molarity, so you don't use the volume information given)

18. What is the concentration of CO_2 in a soft drink that is bottled with a CO_2 partial pressure of 4 atmospheres at 25 °C ? The Henry's Law constant for CO_2 in water is $4.08 \times 10^{-5} \text{ M}/(\text{mm Hg})$

- (A) $2.1 \times 10^{-7} \text{ M}$ (B) $4.1 \times 10^{-5} \text{ M}$ (C) $1.6 \times 10^{-4} \text{ M}$ (D) 0.031 M (E) 0.124 M

$$S_g = k_H P_g$$

P_g is the pressure of CO_2 .

$$P_g = 4 \text{ atm} (760 \text{ mm Hg/atm}) = 3040 \text{ mm Hg}$$

$$S_g = 4.08 \times 10^{-5} \text{ M/(mm Hg)} \times 3040 \text{ mm Hg} = 0.124 \text{ M}$$

19. Which of the following aqueous solutions would have the lowest freezing point?

- (A) 0.10 m NaCl
- (B) 0.10 m CH₃COOH (acetic acid)
- (C) 0.10 m HCl
- (D) 0.10 m Ba(OH)₂
- (E) 0.10 m sugar

$\Delta T_{fp} = K_{fp} m_{solute} i$, and for water, $K_{fp} = -1.86\text{ }^{\circ}\text{C/m}$, so lower freezing point means higher value of $m_{solute} i$ (or you can calculate ΔT_{fp} for each solution):

0.10 m NaCl: electrolyte, with $i = 2$, $\Delta T_{fp} = (-1.86\text{ }^{\circ}\text{C/m}) 0.10\text{ m} (2) = -0.372\text{ }^{\circ}\text{C}$

0.10 m acetic acid, so i lies between 1 (doesn't ionize) and 2 (ionizes completely), so ΔT_{fp} lies between -0.186 and $-0.372\text{ }^{\circ}\text{C}$

0.10 m HCl: strong acid, ionizes completely, so $i = 2$, $\Delta T_{fp} = (-1.86\text{ }^{\circ}\text{C/m}) 0.10\text{ m} (2) = -0.372\text{ }^{\circ}\text{C}$

0.10 m Ba(OH)₂: strong base, with $i = 3$ (make Ba²⁺ and two OH⁻), $\Delta T_{fp} = (-1.86\text{ }^{\circ}\text{C/m}) 0.10\text{ m} (3) = -0.558\text{ }^{\circ}\text{C}$

0.10 m sugar: non-electrolyte, so $i = 1$, $\Delta T_{fp} = (-1.86\text{ }^{\circ}\text{C/m}) 0.10\text{ m} (1) = -0.186\text{ }^{\circ}\text{C}$

20. The vapor pressure of pure water at 25°C is 23.8 mm Hg. What is the vapor pressure of a solution that contains 50 grams water (MW=18.0 g/mol) and 50 grams ethylene glycol (MW = 62.1 g/mol). Ethylene glycol is a nonelectrolyte and assume that its vapor pressure is negligible.

- (A) 18.5 mm Hg
- (B) 11.9 mm Hg
- (C) 23.8 mm Hg
- (D) 6.7 mm Hg
- (E) 3.2 mm Hg

$P_{\text{solvent}} = X_{\text{solvent}} P^{\circ}_{\text{solvent}}$, so need to calculate mole fraction of solvent:

Moles solvent = moles water = 50 g water/(18.0 g/mol) = 2.78 moles water

Moles solute = moles ethylene glycol = 50 g glycol/(62.1 g/mol) = 0.805 moles ethylene glycol

$X_{\text{solvent}} = \text{moles solvent}/(\text{moles solvent} + \text{moles solute})$

$X_{\text{solvent}} = 2.78\text{ moles water}/(2.78\text{ moles water} + 0.805\text{ moles ethylene glycol})$

$X_{\text{solvent}} = 0.775$ (note: don't round off until later !)

$P_{\text{solvent}} = X_{\text{solvent}} P^{\circ}_{\text{solvent}} = 0.775 (23.80\text{ mm Hg}) = 18.46\text{ mm Hg}$

21. (2 pts) Which of the following is a strong acid (pick one) ?

- (A) water
- (B) apple juice
- (C) gasoline
- (D) sulfuric acid
- (E) milk

This question is a double-check of which version of the exam you had...

22. A container has a 1.0 m aqueous solution of potassium chloride in one compartment and a 0.10 m aqueous solution of potassium chloride in the other compartment. The two compartments are separated by a semi-permeable membrane. As the system approaches equilibrium, _____ molecules will move through the membrane from the _____ m solution to the other solution.

- (A) potassium chloride, 0.10
- (B) potassium chloride, 1.0
- (C) water, 0.10
- (D) water, 1.0
- (E) no molecules move through the membrane

Ion concentration is higher in the 1.0 m compartment, so the water concentration is lower in the 1.0 m compartment

This is a semipermeable membrane, so water goes through it, but ions don't.

Water moves from region with higher water concentration (the 0.1 m compartment) to region with lower water concentration (the 1.0 m compartment).

23. 1.00 g of chloroform (CHCl_3 , MW = 119.5 g/mol), a non-electrolyte, is dissolved in 50.0 g of carbon tetrachloride (CCl_4 , MW = 154 g/mol) to give a solution with a volume of 40.0 mL. Assume that the solution is ideal. For CCl_4 , the normal freezing point is -22.3°C , the normal boiling point is 76.8°C , $K_{fp} = -29.8^\circ\text{C/m}$ and $K_{bp} = 5.02^\circ\text{C/m}$.

The freezing point of this solution is:

- (A) -19.3°C (B) -22.3°C (C) -24.2°C (D) -27.3°C (E) -28.5°C

$\Delta T_{fp} = K_{fp} m_{\text{solute}} i$, and $K_{fp} = -29.8^\circ\text{C/m}$, and $i=1$ (nonelectrolyte)

Moles solute = $1.00 \text{ g CHCl}_3 / 119.5 \text{ g/mol} = 8.368 \times 10^{-3} \text{ moles CHCl}_3$

Molality solute = $(8.368 \times 10^{-3} \text{ moles CHCl}_3) / (0.050 \text{ kg solvent}) = 0.167 \text{ m}$

$\Delta T_{fp} = K_{fp} m_{\text{solute}} i$, and $K_{fp} = -29.8^\circ\text{C/m}$, and $i=1$ (nonelectrolyte)

$\Delta T_{fp} = (-29.8^\circ\text{C/m}) (0.167 \text{ M}) (1) = -4.99^\circ\text{C}$

Freezing point of solution = normal freezing point of solvent + ΔT_{fp}

Freezing point of solution = $-22.3^\circ\text{C} - 4.99^\circ\text{C} = -27.3^\circ\text{C}$

Extra Credit (5 pts.)

0.14 liters of 1.00 M NaOH are added to 1 liter of 0.1 M H_3PO_4 , making the total volume 1.14 liters. What is the pH of the resulting solution?

For H_3PO_4 , $K_{a1} = 7.5 \times 10^{-3}$, $K_{a2} = 6.2 \times 10^{-8}$ and $K_{a3} = 3.6 \times 10^{-13}$.

Please answer ON THIS SHEET. Partial credit may be given, but only for work shown on this sheet!

This is a titration you did in lab...

Start with 0.1 moles of H_3PO_4 ...it reacts with 0.1 moles of OH^-



End up with 0.1 moles of H_2PO_4^- and $0.14 - 0.10 = 0.04$ moles of OH^- remain.

As H_2PO_4^- is a weak acid, it reacts with the 0.04 moles of OH^- that remain:



End up with $0.10 - 0.04 = 0.06$ moles of H_2PO_4^- and 0.04 moles of HPO_4^{2-}

This is a buffer (weak acid + conjugate base)

$\text{pH} = \text{pKa} + \log([\text{conjugate base}]/[\text{acid}])$

$[\text{conjugate base}] = [\text{HPO}_4^{2-}] = 0.04 \text{ moles} / 1.14\text{L} = 0.0351 \text{ M}$

$[\text{acid}] = [\text{H}_2\text{PO}_4^-] = 0.06 \text{ moles} / 1.14\text{L} = 0.0526 \text{ M}$

K_{a1} refers to loss of first proton ($\text{H}_3\text{PO}_4 \rightarrow \text{H}_2\text{PO}_4^-$)

K_{a2} refers to loss of second proton ($\text{H}_2\text{PO}_4^- \rightarrow \text{HPO}_4^{2-}$)

so, need to use $\text{pKa}_2 = -\log(K_{a2}) = 7.21$

$\text{pH} = 7.21 + \log(0.0351/0.0526) = 7.21 - 0.18 = 7.03$

(Note: Get the same answer if you don't divide by 1.14L, as the pH of a buffer doesn't change when you dilute it, as it depends on the ratio of concentrations)