2019-2020 ABRHS Science Olympiad

Chemistry Lab Preliminary Test

Acids/Bases and Aqueous Solutions

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Name: ________Key__________ Score: ________100/100__________

Directions:

- You have **50 minutes** to complete this test. Do NOT open the test until instructed.
- You are allowed **one 8.5" x 11" double-sided cheat sheet** and **one stand-alone calculator of any type** for this test.
- For calculations, a correct answer earns full credit, regardless of the work shown. However, work is encouraged for potential partial credit in case the answer is incorrect.
- All answers should be given with the correct units and significant digits (deviations of ±1 are allowed). **0.5 points will be deducted for further deviations.**
- The back of the cover page is a periodic table. A blank page is included for scratch work. You may remove any pages from the test packet for your convenience.

Part I: Multiple Choice (2 pts each, 30 pts total)

1. Under room temperature, the product of concentrations of H^+ and OH^- produced by the auto-ionization of water in a solution is 10^{-24} $mol^2 \cdot L^{-2}$. In this solution, ____________ CANNOT possibly exist in a large quantity.

A. SO_3^{2-}
B. NH_4^+
C. NO_3^-
D. HCO_3^-

2. When temperature increases, which of the following species does NOT increase in its solubility in water?

A. $NaNO_3$
B. KI
C. KCl
D. NH_3

3. x mL of a hydrochloric acid solution with pH = 2.5 will completely react with exactly 10x mL of a strong monoprotic base solution. What is the pH of the basic solution?

A. 9.0
B. 9.5
C. 10.5
D. 11.0

4. There is 10 mL of a strong acid solution with a pH of 1 under room temperature. How to make the pH of the solution become 2?

A. Add water to dilute the solution to 100 mL
B. Add 10 mL of water to dilute the solution
C. Add 10 mL of 0.01M NaOH solution
D. Add 10 mL of 0.01M hydrochloric acid solution

5. Under room temperature, some crystals precipitated out of a glass of saturated table salt solution after it was exposed to air for a while. This is because __________________.

A. the solubility of NaCl decreased
B. the mass fraction of solute in the solution decreased
C. the solution became unsaturated
D. the mass of the solvent decreased

6. Which of the following groups of solids can be separated following the steps "dissolution → filtration → evaporation"?

A. MnO_2 and NaCl
B. CuO and $CaCO_3$
C. Fe and S
D. $KMnO_4$ and $KClO_3$

7. Under room temperature, which of the following statements on solution dilution is correct?

A. After diluting a 1 L 0.1M $Ba(OH)_2$ solution to 2 L by adding water, the final pH is 13.
B. After diluting a hydrochloric acid solution with a pH of 6 to 10 times its original volume by adding water, the final pH is 7.
C. After diluting an H_2SO_4 solution with a pH of 4 to 100 times its original volume by adding water, the $[H^+]$ produced by auto-ionization of water in the solution is 1×10^{-6} M.
D. After diluting a NaOH solution with a pH of 8 to 100 times its original volume by adding water, the final pH is 6.

8. 100 mL of 0.02M $Ba(OH)_2$ solution and 100 mL of 0.02M $NaHSO_4$ solution are mixed under room temperature. Ignoring the change in volume, in the resulting solution _______.

A. pH = 12
B. pH = 2
C. $[H^+]$ due to the auto-ionization of water is equal to 1.0×10^{-2} M
D. the total concentration of solutes is 0.02M

9. After mixing equal volumes of two NaOH solutions (pH = 8 and pH = 10, respectively), the pH of the resulting solution is closest to which of the following?

A. 8.3
B. 8.7
C. 9.3
D. 9.7

10. Using distilled water, an acetic acid solution and a hydrochloric acid solution with the same pH are diluted to m times and n times the original volume, respectively. If the pH of the two solutions is still the same after dilution, what is the relationship between m and n?

A. m < n
B. m = n
C. m > n
D. m = 2n

11. After pouring out ½ of a 10% dilute sulfuric acid solution from a beaker, the remaining solution _______________.

A. has a solute mass fraction of 20%
B. has a halved solute mass fraction, or 5%
C. has the same solute mass fraction as before, which is 10%
D. does not match any of the statements above

12. Let n be Avogadro's number. For 0.2M sodium sulfate, which of the following is correct?

A. A 1 L solution contains 0.2n sodium ions.
B. A 1 L solution contains 0.6n sodium ions and sulfate ions in total.
C. A 3 L solution has a sodium ion concentration of 1.2M.
D. A 2 L solution contains 0.6n sulfate ions.

13. Which of the following gives an accurate description of the relationships among concentrations of ions in solution?

A. In solutions of ammonia, KOH and $Ba(OH)_2$ of the same pH, $[NH_4^+] = [K^+] = [Ba^{2+}]$.
B. After adding 10 mL of 0.1M Na_2CO_3 dropwise into 10 mL of 0.1M hydrochloric acid, $[Na^+] > [Cl^-] > [HCO_3^-] > [CO_3^{2-}]$.
C. After adding a NaOH solution dropwise into a NH_4HCO_3 solution until pH reaches 7, $[NH_4^+] + [Na^+] = [HCO_3^-] + [CO_3^{2-}]$.
D. A 0.2M monoprotic acid HA solution is mixed with 0.1M NaOH of the same volume. $2[OH^-] + [A^-] = 2[H^+] + [HA]$.

14. Which of the following groups of ions can coexist in solution at large quantities?

A. Fe^{3+}, Na^+, Cl^- and I^-
B. Cu^{2+}, K^+, NO_3^- and S^{2-}
C. AlO_2^-, K^+, NO_3^- and OH^-
D. Ba^{2+}, H^+, Cl^- and SO_4^{2-}

15. At 95 °C, the concentration of H^+ in pure water is 10^{-6} mol · L^{-1}. If 0.01 mol of NaOH solid is dissolved in water at 95 °C to make a 1 L solution, then the pH of the resulting solution is ______.

A. 4
B. 10
C. 2
D. 12

Part II: Open Response (70 pts total)

1. Refer to the picture on the cover page. The four characters are Mg, Fe, Cu and Zn, and the solution in the test tubes is hydrochloric acid.

a) Match the characters with their identities in order from left to right. (2 pts)

Mg, Zn, Fe, Cu. (Consider the activity series)

b) Name the gas formed in the test tubes. (1 pt)

Hydrogen gas (H_2).

2. Complete the table. (1 pt each, 8 pts total)

Acid	H_2O	H_3O^+	HPO_4^{2-}	CH_3COOH
Conjugate Base	OH^-	H_2O	PO_4^{3-}	CH_3COO^-
Acid	$C_2H_5NH_3^+$	$[Hg(H_2O)_6]^{2+}$	$[Zn(H_2O)_4(OH)_2]$	H_2F^+
Conjugate Base	$C_2H_5NH_2$	$[Hg(H_2O)_5OH]^+$	$[Zn(H_2O)_3(OH)_3]^-$	HF

3. a) Which of the following is/are characteristic(s) of aqueous solutions? (Write all numbers that apply) (2 pts)

① uniform ② is a mixture ③ colorless ④ transparent ⑤ is a compound

①② (1 pt each; -1 for each wrong answer; 2 pts total)

b) Give two examples of solutions from NATURE or DAILY LIFE (note: while it may not necessarily apply to you, an average typical person from the street does not see 0.1M H_2SO_4 solution or the like in daily life). (2 pts)

Ex. air, seawater (1 pt each, 2 pts total)

c) What are colligative properties? (2 pts)

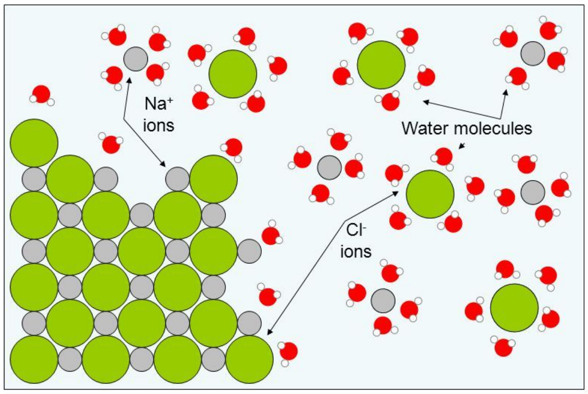
properties of solutions that depend on the number of particles in a volume of solvent (the concentration) and not on the mass or identity of the solute particles.

d) Give two examples of colligative properties. (2 pts)

Ex. boiling point, vapor pressure (1 pt each, 2 pts total)

4. Illustrate the following processes.

a) NaCl dissolves in water. (2 pts)

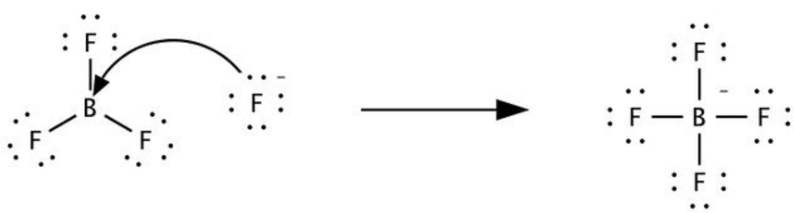


$NaCl(s) + H_2O \rightarrow Na^+(aq) + Cl^-(aq)$

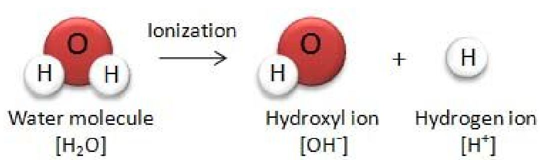
b) Fluoride ion reacts with boron trifluoride to make tetrafluoroborate. (2 pts)

* What type of acid-base reaction is this? ____Lewis____ (1 pt)

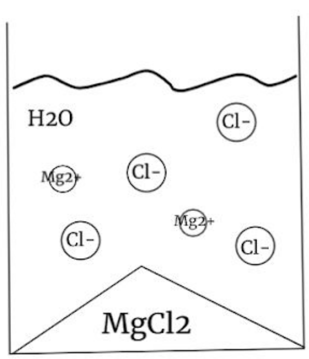
* What is the acid? ___boron trifluoride (BF_3)___ (1 pt)



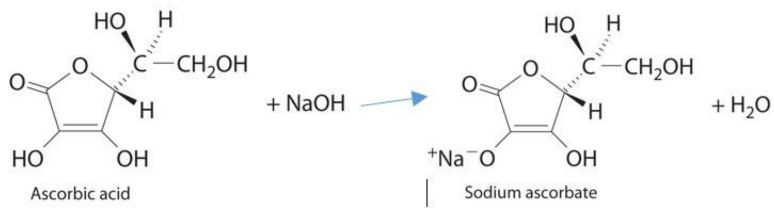
c) Auto-ionization of water. (2 pts)



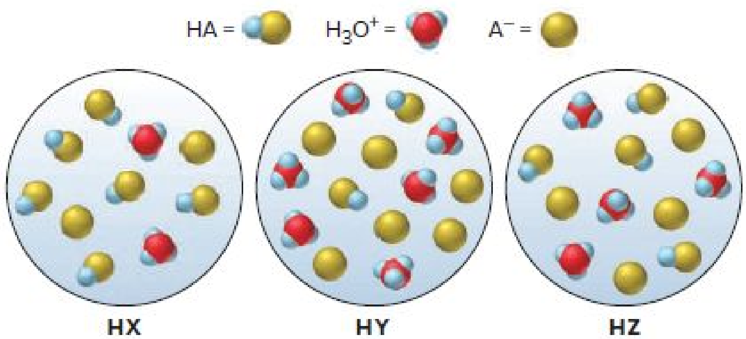
d) 100 grams of magnesium chloride mixed with 100 grams of water. (The solubility of magnesium chloride in water is 54.3 g/100 mL at 20 °C.) (2 pts)



e) The neutralization reaction between sodium hydroxide and Vitamin C (show structural formula). (2 pts)



5. The following scene represents three weak acids HA (where A = X, Y, or Z) dissolved in water (H_2O is not shown):



a) Rank the acids in order of increasing Ka. (1 pt)

HX < HZ < HY

b) Rank the acids in order of increasing pKa. (1 pt)

HY < HZ < HX

c) Rank the conjugate bases in order of increasing pKb. (1 pt)

HX < HZ < HY

d) If equimolar amounts of the sodium salts of the acids (NaX, NaY, and NaZ) were dissolved in water, which solution would have the highest pOH? Which solution would have the lowest pH? (2 pts)

Highest pOH: **NaY**; (1 pt)

Lowest pH: **NaY** (1 pt)

6. Consider the following five solutions with the same molar concentration:

① CH_3COONa ② CH_3COONH_4 ③ CH_3COOH ④ $NH_3 \cdot H_2O$ ⑤ NH_4Cl

a) Rank the solutions in order of descending pH (write the numbers, not names; indicate which ones are equal, if any): ④ > ① > ② > ⑤ > ③ (2 pts)

b) Rank the solutions in order of descending total concentrations of ions (write the numbers, not names; indicate which ones are equal, if any): ① = ⑤ > ② > ③ = ④ (2 pts)

7. A solution is prepared by adding 29.3 g of menthol ($C_{10}H_{20}O$) to 0.0590 kg of chloroform.
a) What is its boiling point? (The boiling point of pure chloroform is 61.2 °C, and the boiling point constant for chloroform is 3.85 °C/m.) (2 pts)

Molality of menthol: $\frac{29.3\ g}{156.267\ g/mol} \times \frac{1}{0.0590\ kg}$ = 3.18 m (1 pt)

$\Delta T = i K_b m$

ΔT = (1)(3.85 °C/m)(3.18m)

ΔT = 12.2 °C

B.P. = 61.2 °C + 12.2 °C = **73.4 °C** (1 pt)

b) What is the concentration of menthol expressed in molarity? (The density of menthol is 0.89 g/mL, and the density of chloroform is 1.492 g/mL at 25 °C.) (1 pt)

1.492 g/mL = 1.492 kg/L

$V_{total} = V_{menthol} + V_{chloroform}$ = 29.3 g × $\frac{1\ mL}{0.89\ g} \times \frac{1\ L}{1000\ mL}$ + 0.0590 kg × $\frac{1\ L}{1.492\ kg}$

= 0.0725 L

$\frac{29.3\ g}{156.267\ g/mol} \times \frac{1}{0.0725\ L}$ = **2.59 M** (1 pt)

8. After diluting an H_2SO_4 solution with a pH of 5 to 500 times its original volume, what is the approximate ratio between $[H^+]$ and $[SO_4^{2-}]$? (3 pts)

$H_2SO_4 \rightarrow 2H^+ + SO_4^{2-}$

$[H^+]_{initial} = 10^{-pH} = 10^{-5}$ M, $[SO_4^{2-}]_{initial} = \frac{10^{-5}}{2}$ M (1 pt)

After the dilution, $[H^+]$ approaches 10^{-7} M, and $[SO_4^{2-}] = \frac{\frac{10^{-5} M}{2}}{500} = 1 \times 10^{-8}$ M. (1 pt)

$[H^+] : [SO_4^{2-}]$ ≈ 10 : 1 (1 pt)

9. 100 mL of a 0.1M $Ba(OH)_2$ solution and 50 mL of a 0.1M Na_2CO_3 solution are mixed together. A student sets up a titration and adds 0.1M HCl into the mixture dropwise while swirling.
a) When the pH reaches 7, the student stops. What is the volume of HCl added? (2 pts)

$Ba(OH)_2 + Na_2CO_3 \rightarrow BaCO_{3(s)} + 2NaOH$

The equation for the titration is $H^+ + OH^- \rightarrow H_2O$.

All OH^- from the original mixture will be floating in the solution in the ionic form.

mol OH^- = 0.1M $Ba(OH)_2$ × 100 mL $Ba(OH)_2$ × $\frac{1\ L}{1000\ mL}$ × $\frac{2\ mol\ OH^-}{1\ mol\ Ba(OH)2}$ = 0.02 mol

(1 pt)

V_{HCl} =0.02 mol OH^- × $\frac{1\ mol\ H^+}{1\ mol\ OH^-}$ × $\frac{1\ mol\ HCl}{1\ mol\ H^+}$ × $\frac{1\ L\ HCl}{0.1\ mol\ HCl}$ = **0.2 L = 200 mL**

(1 pt)

b) If the student then adds 0.1M acidified $AgNO_3$ into the solution until all Cl^- completely precipitates, what is the minimum volume of $AgNO_3$ solution needed? (2 pts)

$Ag^+ + Cl^- \rightarrow AgCl_{(s)}$

mol Cl^- = 0.2 L × $\frac{0.1\ mol\ HCl}{1\ L\ HCl}$ × $\frac{1\ mol\ Cl^-}{1\ mol\ HCl}$ = 0.02 mol (1 pt)

V_{AgNO3} = 0.02 mol Cl^- × $\frac{1\ mol\ Ag^+}{1\ mol\ Cl^-}$ × $\frac{1\ mol\ AgNO3}{1\ mol\ Ag^+}$ × $\frac{1\ L\ AgNO3}{0.1\ mol\ AgNO3}$

= **0.2 L = 200 mL** (1 pt)

10. What is the pH of a 0.300M solution of benzoic acid (Ka = 6.46 × 10^{-5})? (2 pts)

Since K_a is small enough, the assumption holds.

R	HBz +	H_2O ⇋	Bz^- +	H_3O^+
I	0.300	-	0	0
C	-x	-	+x	+x
E	0.300	-	x	x

$K_a = \frac{[H_3O^+][Bz^-]}{[HBz]}$, $6.46 \times 10^{-5} = \frac{x^2}{0.300}$, $x = 4.40 \times 10^{-3}$ (1 pt)

pH = -log(x) = **2.356** (1 pt)

OR

Use shortcut: pH = -log $\sqrt{K_a C}$ = -log $\sqrt{6.46 \times 10^{-5} \times 0.300}$ = **2.356**

11. How many grams of sodium formate (HCOONa) do you need to add to 400. mL of 1.00M formic acid to form a buffer with pH = 3.500? (K_a = 1.77 × 10^{-4}) (2 pts)

Henderson-Hasselbalch equation: pH = pK_a + log $\frac{[HCOO^-]}{[HCOOH]}$

pKa = -log(1.77 × 10^{-4}) = 3.752

$3.500 = 3.752 + \log \frac{[HCOO^-]}{1.00}$, $[HCOO^-] = 0.560M$ (1 pt)

g HCOONa = 400. mL × $\frac{1\ L}{1000\ mL} \times \frac{0.560\ mol}{1\ L} \times \frac{68.0069\ g}{1\ mol}$ = **15.2 g** (1 pt)

12. When using neutralization titration to determine the content of NaOH in a mixture of NaOH and Na_2CO_3 solutions, a student first adds excess barium chloride to completely precipitate out Na_2CO_3 as $BaCO_3$, then titrate the solution with standardized hydrochloric acid (using phenolphthalein as the indicator).

a) Why will adding hydrochloric acid into the NaOH solution mixed with $BaCO_3$ precipitate not cause the $BaCO_3$ to dissolve but allow the student to determine the content of NaOH? (2 pts)

When hydrochloric acid is added to NaOH solution mixed with $BaCO_3$ precipitate, the hydrochloric acid will first react with the NaOH. It will only react with the $BaCO_3$ when NaOH is completely consumed, so the $BaCO_3$ will not dissolve.

b) How will the color of the indicator change at the endpoint? (1 pt)

From pink to colorless.

c) During the titration, if the endpoint was not reached until the titrant level fell under the stopcock of the buret, the recorded volume of hydrochloric acid used will be ___too low__ (too high/accurate/too low). (1 pt)

d) Can the student use methyl orange (pH range = 3.1–4.4) as the indicator instead? __No__ (Yes/No) (1 pt). If methyl orange is used as the indicator, the content of NaOH calculated based on the results will be _______too high________ (too high/accurate/too low) (1 pt).

13. One of the raw materials of the chlor-alkali industry, saturated table salt solution, contains a certain quantity of ammonium ions. During electrolysis, these ammonium ions will form the extremely unstable compound nitrogen trichloride, which can easily cause an explosion.

a) Nitrogen trichloride is readily hydrolyzed. Aside from ammonia gas, its initial products from hydrolysis also include _____HClO______. (1 pt) $NCl_3 + 3H_2O \rightarrow NH_3 + 3HOCl$

b) To remove the ammonium ions from saturated table salt solution, one method is to introduce chlorine gas under basic conditions to react and form nitrogen gas. The net ionic equation for this reaction is ________$3Cl_2 + 2NH_4^+ + 8OH^- \rightarrow N_2 + 6Cl^- + 8H_2O$________ (2 pts). One advantage of choosing this method in industry is using the product of chlor-alkali industry, chlorine gas, as raw material creates convenience and does not introduce other impurities to the process (1 pt).

c) Excess chlorine gas is removed using $Na_2S_2O_3$. In the reaction, $S_2O_3^{2-}$ is oxidized and becomes SO_4^{2-}. If there are 1×10^{-3} moles of chlorine gas in excess, then theoretically the SO_4^{2-} produced will be ___**5×10^{-4}**__ mol. (3 pts)

Cl_2 is reduced to Cl^-, and the total number of electrons gained by 1×10^{-3} moles of Cl_2 is 2×10^{-3} moles ($Cl_2 + 2e^- \rightarrow 2Cl^-$). In a redox reaction, the total number of electrons gained by the oxidizing agent is always equal to the total number of electrons lost by the reducing agent. Hence, S should lose 2×10^{-3} moles of electrons in total. The S in $S_2O_3^{2-}$ has an oxidation number of +2, while the S in SO_4^{2-} has an oxidation number of +6, so each S atom should lose 4 electrons. Theoretically, the quantity of SO_4^{2-} produced is 2×10^{-3} mol/4 = 5×10^{-4} mol.

d) Formaldehyde is widely used in production and experiments to determine the nitrogen content of a sample. The reaction between formaldehyde and ammonium ion is $4NH_4^+ + 6HCHO \rightarrow (CH_2)_6N_4H^+ + 3H^+ + 6H_2O$, with $(CH_2)_6N_4H^+$ being a monoprotic acid. The procedures are as follows:

① Formic acid is often contained in formaldehyde solutions. Pour *b* mL of formaldehyde solution (excess) into an Erlenmeyer flask and add one drop of phenolphthalein. Neutralize the solution with *c* mol/L NaOH. The initial reading on the buret is V_1 mL; when the solution appears to be light pink, the reading on the buret V_2 mL.

② Add *a* mL of a sample of saturated table salt solution and let the flask stand for several minutes.

③ Add 1–2 more drops of phenolphthalein, and use the same NaOH solution to titrate until light pink shows. The reading on the buret is V_3 mL.

The nitrogen content of the sample of table salt solution is ___ $\frac{14000c\,(V3 - V2)}{a}$ ___ mg/L (express in terms of the variables). (3 pts)

The quantity of H^+ produced by the reaction between formaldehyde and ammonium ions is determined in the second titration to be $c(V_3 - V_2) \times 10^{-3}$ mol. The balanced equation shows that the mole ratio between NH_4^+ and H^+ is 4 : 4, or 1 : 1 (there are $3H^+$ and 1 monoprotic acid). Hence, the nitrogen content of the sample is

$$\frac{c\,(V3 - V2) \times 10^{-3} mol \times 14\ g/mol}{a \times 10^{-3}\ L} = \frac{14000c\,(V3 - V2)}{a}\ \text{mg/L.}$$