Taipei Municipal YangMing High School

Teacher Recruitment at 2024

Paper and Pencil Test

Subject: Chemistry

This test consists of two parts: part I, single-choice questions (40 points); part II, short-answer questions (60 points).

Part I. Single-choice questions (1-20), 2 points for each question.

1. For $[H^+] = (8.0 \pm 0.4) \times 10^{-5}$ M, pH = 4.10 ± s. s = ?
   (A) 0.01 (B) 0.02 (C) 0.03 (D) 0.04

2. What is the volume (in mL) of 1.0 M NaOH(aq) that must be added to 1.0 M, 60 mL HA(aq) to make a buffer solution with pH = 6.0? $pK_a = 5.7$ for HA
   (A) 20 (B) 30 (C) 40 (D) 50

3. Ionization of water is an endothermic process with $pK_w = 14.0$ at 25°C. For pure water at 37°C, which of the following relations is correct?
   (A) $pK_w > 14.0$ (B) pH = 7.0 (C) pOH > 7.0 (D) $pK_w = 2$ pH

4. For two monoprotic acids (HA, HB) and their conjugate bases (A^-, B^-), the following relations are known: $HA + B^- \rightleftharpoons A^- + HB$, $K > 1$ and $pK_b(A^-) < 7.0$. Which of the following order of K's is correct?
   (A) $K_b(B^-) > K_a(HB) > K_a(HA) > K_b(A^-)$
   (B) $K_b(A^-) > K_b(B^-) > K_a(HA) > K_a(HB)$
   (C) $K_b(B^-) > K_b(A^-) > K_a(HA) > K_a(HB)$
   (D) $K_b(B^-) > K_a(HA) > K_b(A^-) > K_a(HB)$

5. The solubility of $Ag_2CrO_4(s)$ in water is 10000 times that of $Ag_2CrO_4(s)$ in 0.020 M $AgNO_3(aq)$. What is the K_{sp} for Ag_2CrO_4?
   (A) 2×10^{-8} (B) 4×10^{-10} (C) 1×10^{-12} (D) 4×10^{-12}

6. Consider the concentration cell: Cu | Cu^{2+} (5.0×10^{-5} M) || Cu^{2+} (0.50 M) | Cu. What is the cell potential (in volt) at 25°C?
   (A) 0.06 (B) 0.12 (C) 0.18 (D) 0.24

7. For the condensation of water vapor at 1 atm and 25°C ($H_2O(g) \rightarrow H_2O(l)$), which of the following relations is correct?
   (A) $\Delta G < 0$ (B) $w < 0$ (C) $\Delta S > 0$ (D) $q > 0$

8. For an isothermal and reversible compression of an ideal gas, which of the following relations is correct?
   (A) $\Delta H < 0$ (B) $\Delta G = 0$ (C) $q > 0$ (D) $\Delta S < 0$

9. Adding $CH_4(g)$ into a fixed-volume flask containing $O_2(g)$ until the pressure is tripled, how many times its density will be? ($d_{final}/d_{initial} = ?$)
   (A) 2 (B) 3 (C) 4 (D) 6

10. Which of the following elements has the lowest second ionization energy?
    (A) B (B) C (C) N (D) O

11. For Ag^+ ion in its ground state, what is the number of electrons that have $m_l = 0$ and $m_s = -1/2$? ($Z = 47$ for Ag)
    (A) 9 (B) 10 (C) 18 (D) 20

12. Which of the following compounds would have the largest melting point?
    (A) NaCl (B) KCl (C) MgO (D) $MgCl_2$

13. One mole of an ideal gas ($C_v = 20\ J \cdot K^{-1} \cdot mol^{-1}$), initially at 1.0 atm and 300 K, absorbs 100 J of heat and performs 500 J of work in a certain process. What is the final temperature (in K) of the gas?
    (A) 280 (B) 290 (C) 300 (D) 320

14. Decomposition of 2.76 g M_2CO_3 yields 1.88 g M_2O. What is the atomic mass of M?
    (A) 9 (B) 23 (C) 39 (D) 85

15. For a triprotic acid H_3A with $pK_1 = 3.0$, $pK_2 = 6.0$ and $pK_3 = 9.0$, which of the following relations is correct?
    (A) $[H_3A] = [A^{3-}]$ at pH = 7.0
    (B) $[HA^{2-}]/[A^{3-}] = 10$ at pH 7.0
    (C) $[H_2A^-] > [HA^{2-}]$ at pH 6.5
    (D) $[H_3A] > [HA^{2-}]$ at pH 5.0

16. Which of the following statements is correct?
    (A) a saturated solution contains a high concentration of solute.
    (B) the solubility of solids always increases with temperature.
    (C) a saturated solution involves a dynamic equilibrium between the solid and its solution.
    (D) a supersaturated solution involves a dynamic equilibrium between the solid and its solution.

17. Which operation will increase the quantity of product for the exothermic reaction: $2SO_2(g) + O_2(g) \rightleftharpoons 2SO_3(g)$
    (A) a decrease in volume of container
    (B) an increase in temperature
    (C) increasing P by adding some argon
    (D) adding a catalyst

18. Consider the equilibrium: $PCl_5(g) \rightleftharpoons PCl_3(g) + Cl_2(g)$, $K_c = 0.025$ at 400 K. If 0.5 mol of PCl_5 is placed in a 1.0 L container at 400 K and is allowed to reach equilibrium, what is the total pressure (in atm) of the gases?
    (A) 5 (B) 10 (C) 15 (D) 20

19. For an ideal gas, which of the following sets of variables has a linear relationship?
    (A) P vs. 1/V (B) V vs. T (C) PV vs. T (D) P/T vs. density

20. It took 2 min for 0.20 L of H_2 to effuse through a pin hole. How long will it take (in min) for 0.10 L of O_2 to effuse under identical conditions?
    (A) 2 (B) 4 (C) 8 (D) 16

Part II. Short-answer questions (21-26); 10 points for each question.

Question 26 must be answered in English; other questions can be answered in Chinese.

21. A certain liquid (X) has a normal boiling point of 353 K. The densities (in g/L) of the vapor X in equilibrium with its liquid at 300 K and 353 K are 0.50 and 2.7, respectively. Assume the vapor behaves ideally, answer the following questions.

(A) Find the molar mass of X. 3%

(B) Find the vapor pressure of liquid X at 300 K. 2%

(C) If the saturated vapor of X at 353 K in a 2.0 L glass flask is cooled to 300 K, what is the mass of X that the will be condensed? 2%

(D) If X is a hydrocarbon containing 92.3% carbon, what are the empirical formula and molecular formula of X? 3%

22. A battery is constructed from two half cells: $Zn|Zn^{2+}$(1.0 M) and $Mn|Mn^{2+}$(1.0 M); the volume of each electrolyte solution is 300 mL. The battery is allowed to discharge at a constant current of 9.65 amperes. Given that: F = 96500 $C \cdot mol^{-1}$; $E° = -0.76$ V for Zn^{2+}/Zn and -1.18 V for Mn^{2+}/Mn. Answer the following questions.

(A) Indicate the anode, cathode, and direction of electron flow of the cell. 3%

(B) Calculate the standard cell potential. 2%

(C) The equilibrium constant of the cell reaction is K; log K = ? 2%

(D) Find $[Zn^{2+}]$ after 10 min. of discharging. 3%

23. One mole of an ideal gas ($C_v = 2R$), initially at X, undergoes three reversible steps of a cycle as shown below:

$$\text{X (3 atm, 300 K)} \xrightarrow{(1)} \text{Y (1 atm)} \xrightarrow{(2)} \text{Z (0.5 atm)} \xrightarrow{(3)} \text{X}$$

(1) isothermal; (2) isochoric (fixed V); (3) adiabatic

Answer the following questions. ($\ln 3 = 1.1$)

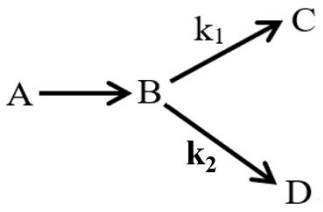
(A) Find the temperature (T) at state Z. 2%

(B) Find the work done (w) for step (3). 2%

(C) Find the change in enthalpy (ΔH) for step (2). 3%

(D) Find the heat (q) involved in a cycle. 3%

24. After people take the medicine X, it can be absorbed into the body through pathway A→B and enter the blood. Medicine in the blood can reduce its concentration through decomposition (B→C) or excretion (B→D), as shown in the figure below:



Assume that the process A→B is much faster than those of B→C and B→D. Therefore, each time a medicine with a dose of $[X]_o$ is taken, it can be regarded as immediately producing a concentration of $[X]_b$ (= 0.020 mM) of X in the blood. Assume that B→C and B→D are both first-order processes, and their rate constants are k_1 (= 0.075 h^{-1}) and k_2 (= 0.025 h^{-1}), respectively. If a person takes the same dose ($[X]_o$) of the medicine every t hour, answer the following questions.

(A) Just after taking the medicine for the n^{th} time, its concentration in the blood is equal to $[P]_n$. Express $[P]_n$ as a function of $[X]_b$, k_1, k_2 and t. 3%

(B) Continue to take the medicine every 6 hours for a long period of time ($n \to \infty$), calculate $[P]_\infty$ (in mM)? 3%

(C) Find the half-life of the medicine in the blood. 2%

(D) What proportion of the decrease in medicine concentration in the blood is caused by decomposition? 2%

25. Extraction and spectroscopic methods can be used to determine the dissociation constant (K_a) of a monoprotic organic acid (HA) and its distribution coefficient (K_d) between the organic phase and the aqueous phase. When extracting organic acids, it is assumed that only HA is soluble in the organic layer, and its concentration is $[HA]_{org}$; while HA and A^- exist in the aqueous layer, and their concentrations are $[HA]_{aq}$ and $[A^-]_{aq}$, respectively. The distribution coefficient is defined as $K_d = [HA]_{org}/[HA]_{aq}$.

In an extraction experiment, take 10-mL of an aqueous solution containing 3.5 mM HA at pH 5.0; extract it with 15-mL of an organic solvent. Separate the mixed solution into aqueous and organic layers. Take 1.0 mL of the aqueous layer; put it into a 1.0-cm (path length) cuvet; measure the absorbances at 400 nm and 450 nm; the observed absorbances are 0.30 and 0.62, respectively. Given the following information: molar absorptivity ε (in $M^{-1}.cm^{-1}$): $\varepsilon_{400}(HA) = 2000$, $\varepsilon_{400}(A^-) = 250$, $\varepsilon_{450}(HA) = 200$, $\varepsilon_{450}(A^-) = 1500$. Answer the following questions.

(A) Find $[HA]_{aq}$ and $[A^-]_{aq}$ in the aqueous layer. 4%

(B) Find $[HA]_{org}$ in the organic layer. 2%

(C) Find the acid dissociation constant K_a. 2%

(D) Find the distribution coefficient K_d. 2%

26. Explain the following terms. 2 points for each term.

(A) mean free path

(B) isotonic solutions

(C) cathodic protection

(D) ion-selective electrode

(E) amphoteric substance