Chemistry Lab - Round 1
2014-2015

Name: Key Score: 38/38

Instructions: This is the first round of Chemistry Lab testing for the 2014 - 2015 Science Olympiad season. You will have 30 minutes to complete this exam which covers topics in chemical reactions, stoichiometry, and chemical kinetics. In your responses, please use the appropriate amount of significant figures. Also, you may use the provided periodic table and a scientific calculator.

True or False (1 point each)

Please circle the correct answer.

1. True / False: The coefficients of a balanced chemical equation show the stoichiometric ratio of masses.
2. True / False: The mole is a fundamental SI unit.
3. True / False: The study of the tendency of a reaction to occur is known as "chemical kinetics."
4. True / False: Avogadro's constant has an order of magnitude (i.e. the power of 10) of 32.
5. True / False: The molar mass of a substance describes the number of grams in one mole of that substance.

Multiple Choice (1 point each)

Please write the letter of the best answer next to the problem number.

1. How many moles of compound are in 20.15 g of $CuSO_4 \cdot 5\,H_2O$?

   (a) 3.216×10^3 mol (b) 8.070×10^{-2} mol (c) 1.262×10^{-1} mol (d) 2.49×10^2 mol

2. When the chemical reaction for the combustion of propane is balanced with the smallest possible whole-number coefficients, what is the sum of its coefficients?

   (a) 12 (b) 13 (c) 14 (d) 25 (e) 26

3. A sample of an unknown substance containing carbon, hydrogen, and oxygen was analyzed and found to contain 40.00% carbon and 6.71% hydrogen. Determine the empirical formula of this compound.

   (a) CH_2O (b) $C_2H_3O_2$ (c) CHO (d) CH_2 (e) None of these

4. Collision theory states that which of the following *must* be true for a reaction to occur?

   I. Colliding particles must have sufficient kinetic energy.
   II. Colliding particles must hit each other from the correct direction and with the correct orientation.
   III. The total energy of the colliding particles must not exceed the activation energy.

   (a) I Only (b) II Only (c) I and II Only (d) I and III Only (e) I, II, and III

Free Response

Please show your work and box numerical answers.

Part I - Stoichiometry

1. The following reaction is used in commercial Breathalyzer^{TM}tests:

   $3\,C_2H_5OH + 2\,K_2Cr_2O_7 + 8\,H_2SO_4 \longrightarrow 2\,Cr_2(SO_4)_3 + 3\,CH_3COOH + 2\,K_2SO_4 + 11\,H_2O$

   What mass of ethanol is required to react completely with 6.35 g of potassium dichromate.

   $\frac{6.35\,\text{g}}{294.185\,\text{g mol}^{-1}} \times \frac{3\,\text{mol}_{C_2H_5OH}}{2\,\text{mol}_{K_2Cr_2O_7}} \times 46.068\,\text{g mol}^{-1} = \boxed{1.49\,\text{g}}$

2. The following unbalanced reaction shows the thermal decomposition of sodium bicarbonate (baking soda): $NaHCO_3(s) \xrightarrow{\Delta} Na_2CO_3(s) + H_2O(g) + CO_2(g)$

   (a) Write the balanced chemical equation.

   $2\,NaHCO_3(s) \longrightarrow Na_2CO_3(s) + H_2O(g) + CO_2(g)$

   (1 point for coefficients)

   (b) When doing this decomposition in a lab, how can you tell when all the $NaHCO_3$ has decomposed? (Note: Both Na_2CO_3 and $NaHCO_3$ are white powders.)

   After heating the sample and letting it cool to room temperature, mass the sample (including the crucible and lid). Reheat the sample, let it cool to room temperature, and re-mass the apparatus. If the mass has not changed significantly, then the decomposition is complete.

   (2 points: 1 point for re-massing + 1 point for cooling to room temperature)

   (c) Suppose you started with 25.000 g of $NaHCO_3$ and found that the mass of Na_2CO_3 produced through the reaction is 13.813 g, what was your percent yield?

   $$\%\text{ yield} = \frac{\textit{experimental yield}}{\textit{theoretical yield}} = \frac{13.813\,\text{g}}{\frac{25.000\,\text{g}}{84.007\,\text{g mol}^{-1}} \times \frac{1\,\text{mol}_{Na_2CO_3}}{2\,\text{mol}_{NaHCO_3}} \times 143.008\,\text{g mol}^{-1}} = \boxed{87.586\,\%}$$

   (1 point)

   (d) If during the final massing of the product, some dirt fell on the balance, how would the resulting percent yield differ from the actual percent yield? Explain.

   Because there is extra mass on the scale, it will appear as if there is more sodium carbonate than there actually is. Thus, the apparent percent yield will be greater than the actual percent yield.

   (2 points: 1 point for correct answer + 1 point for explanation)

Part II - Chemical Kinetics

3. Consider the generic reaction $aA + bB \longrightarrow cC$ with an activation energy of 10.0 kJ/mol. The following experiment was done at 298K to determine the rate law. Different initial concentrations of reactants were used and the initial rate was recorded. All concentrations are measured in mol/L.

[A]	[B]	Initial rate (M/s)
2.0	3.0	13.5
4.0	3.0	27.0
4.0	6.0	108.0

   (a) Write the rate law for this reaction using k as the rate constant.
   $rate = k[A][B]^2$ **(1 point)**

   (b) If [A] is doubled and [B] is tripled, how will the rate of reaction change?
   The rate will increase by 18 times. **(1 point)**

   (c) Find k at 25 °C (298 K).
   $k = \dfrac{rate}{[A][B]^2} = \boxed{0.750\,\mathrm{L^2\,mol^{-2}\,s^{-1}}}$ **(2 points: 1 for number + 1 for units)**

   (d) Find k at 64 °C (Assume frequency factor is constant with temperature for (d) and (e)).
   Use the combined Arrhenius equation: $\ln\left(\dfrac{k_1}{k_2}\right) = \dfrac{E_A}{R}\left(\dfrac{1}{T_2} - \dfrac{1}{T_1}\right)$. Make sure to match up the units for E_A and R.
   $k = \boxed{1.20\,\mathrm{L^2\,mol^{-2}\,s^{-1}}}$ **(2 points: 1 for number + 1 for units)**

   (e) At what temperature does $k = 0.88$? (Note: units excluded for testing purposes)
   Use above formula again.
   $\boxed{310\ \mathrm{K}}$ **(1 point)**

4. Write the balanced chemical equations for the following processes. Include state symbols.

   3 points each: 1 for products, 1 for coefficients, 1 for state symbols (coefficient and state symbol points only received for correct products)

   (a) A strip of magnesium is burned.
   $2\,Mg(s) + O_2(g) \longrightarrow 2\,MgO(s)$

   (b) Solutions of silver nitrate and sodium chloride are mixed.
   $AgNO_3(aq) + NaCl(aq) \longrightarrow AgCl(s) + NaNO_3(aq)$

   (c) Hydrogen chloride gas is bubbled through water.
   $HCl(g) + H_2O(l) \longrightarrow H_3O^+(aq) + Cl^-(aq)$

   (d) Powdered sodium bicarbonate is added to aqueous acetic acid.
   $NaHCO_3(s) + CH_3COOH(aq) \longrightarrow NaC_2H_3O_2(aq) + H_2O(l) + CO_2(g)$

   (e) Butane is burned in air.
   $2\,C_4H_{10}(g) + 13O_2(g) \longrightarrow 8\,CO_2(g) + 10H_2O(g)$