

**2018****AP<sup>®</sup>** **CollegeBoard**

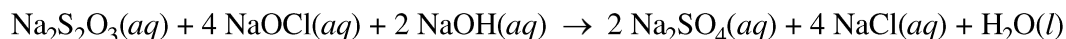
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# AP Chemistry

## Scoring Guidelines

## 2018 SCORING GUIDELINES

## Question 1



A student performs an experiment to determine the value of the enthalpy change,  $\Delta H_{\text{rxn}}^\circ$ , for the oxidation-reduction reaction represented by the balanced equation above.

Determine the oxidation number of Cl in NaOCl.

|    |                                           |
|----|-------------------------------------------|
| +1 | 1 point is earned for the correct answer. |
|----|-------------------------------------------|

Calculate the number of grams of  $\text{Na}_2\text{S}_2\text{O}_3$  needed to prepare 100.00 mL of 0.500 M  $\text{Na}_2\text{S}_2\text{O}_3$ (

|                                                                                                                                                                                                                                           |                                                                                                                                                                                                                                                                               |
|-------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|-------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| $100.00 \text{ mL} \times \frac{0.500 \text{ mol Na}_2\text{S}_2\text{O}_3}{1000 \text{ mL}} \times \frac{158.10 \text{ g Na}_2\text{S}_2\text{O}_3}{1 \text{ mol Na}_2\text{S}_2\text{O}_3}$ $= 7.90 \text{ g Na}_2\text{S}_2\text{O}_3$ | <p>1 point is earned for the correct number of moles of <math>\text{Na}_2\text{S}_2\text{O}_3</math> (may be implicit).</p> <p>1 point is earned for the correct calculation of mass of <math>\text{Na}_2\text{S}_2\text{O}_3</math> consistent with the number of moles.</p> |
|-------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|-------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|

In the experiment, the student uses the solutions shown in the table below.

| Solution                              | Concentration (M) | Volume (mL) |
|---------------------------------------|-------------------|-------------|
| $\text{Na}_2\text{S}_2\text{O}_3(aq)$ | 0.500             | 5.00        |
| $\text{NaOCl}(aq)$                    | 0.500             | 5.00        |
| $\text{NaOH}(aq)$                     | 0.500             | 5.00        |

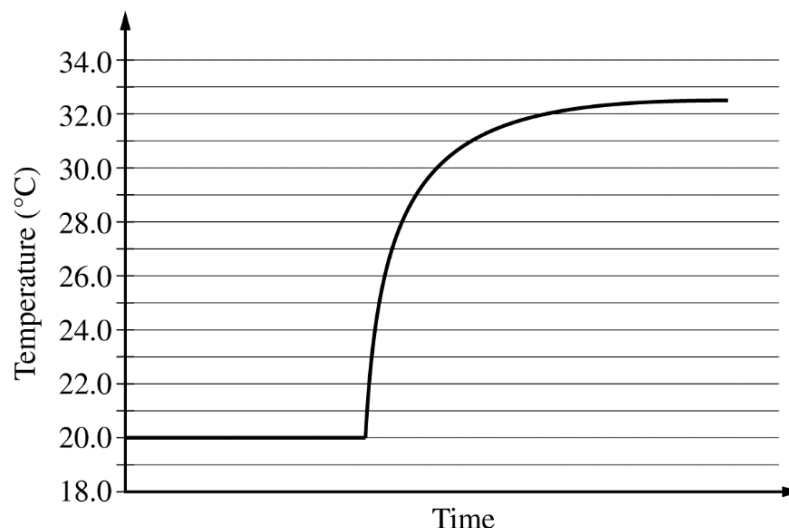
Using the balanced equation for the oxidation-reduction reaction and the information in the table above, determine which reactant is the limiting reactant. Justify your answer.

|                                                                                                                                                                                                                                        |                                                                                                        |
|----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|--------------------------------------------------------------------------------------------------------|
| <p>NaOCl is the limiting reactant.</p> <p>Given that equal numbers of moles of each reactant were present initially, it follows from the coefficients of the reactants in the balanced equation that NaOCl will be depleted first.</p> | <p>1 point is earned for identifying limiting reactant <u>and</u> providing a valid justification.</p> |
|----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|--------------------------------------------------------------------------------------------------------|

## 2018 SCORING GUIDELINES

## Question 1 (continued)

The solutions, all originally at 20.0°C, are combined in an insulated calorimeter. The temperature of the reaction mixture is monitored, as shown in the graph below.



According to the graph, what is the temperature change of the reaction mixture?

|                                                                                                                                        |                                                  |
|----------------------------------------------------------------------------------------------------------------------------------------|--------------------------------------------------|
| From the graph the final temperature is 32.5°C.<br>$\Delta = T_f - T_i = 32.5^\circ\text{C} - 20.0^\circ\text{C} = 12.5^\circ\text{C}$ | 1 point is earned for the correct value $\Delta$ |
|----------------------------------------------------------------------------------------------------------------------------------------|--------------------------------------------------|

The mass of the reaction mixture inside the calorimeter is 15.21 g.

- (i) Calculate the magnitude of the heat energy, in joules, that is released during the reaction. Assume that the specific heat of the reaction mixture is 3.94 J/(g·°C) and that the heat absorbed by the calorimeter is negligible.

|                                                                                                                      |                                                                                                         |
|----------------------------------------------------------------------------------------------------------------------|---------------------------------------------------------------------------------------------------------|
| $q = mc\Delta T$<br>$= (15.21 \text{ g})(3.94 \text{ J/(g}\cdot^\circ\text{C)})(12.5^\circ\text{C}) = 749 \text{ J}$ | 1 point is earned for the correct calculation<br>$q$ consistent with the $\Delta T$ value from part (i) |
|----------------------------------------------------------------------------------------------------------------------|---------------------------------------------------------------------------------------------------------|

- (ii) Using the balanced equation for the oxidation-reduction reaction and your answer to part (c), calculate the value of the enthalpy change of the reaction,  $\Delta H_{\text{rxn}}^\circ$ , in kJ/mol<sub>rxn</sub>. Include the appropriate algebraic sign with your answer.

## 2018 SCORING GUIDELINES

## Question 1 (continued)

|                                                                                                                                                                                                                                                                                                                                                                      |                                                                                                                                                                                                                                                                                          |
|----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| $\text{NaOCl} = 5.00 \text{ mL} \times \frac{0.500 \text{ mol NaOCl}}{1000 \text{ mL NaOCl}} = 0.00250 \text{ mol NaOCl}$ $= 0.00250 \text{ mol NaOCl} \times \frac{1 \text{ mol}_{rxn}}{4 \text{ mol NaOCl}} = 0.000625 \text{ mol}_{rxn}$ $\Delta H_{rxn}^{\circ} = \frac{-0.749 \text{ kJ}}{0.000625 \text{ mol}_{rxn}} = -1.20 \times 10^3 \text{ kJ/mol}_{rxn}$ | <p>1 point is earned for correctly calculating the value of mol consistent with the limiting reactant in part</p> <p>1 point is earned for a negative <math>\Delta H_{rxn}^{\circ}</math> obtained by dividing the calculated value of <math>q</math> by the calculated value of mol</p> |
|----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|

→ student repeats the experiment, but this time doubling the volume of each of the reactants, as shown in the table below.

| Solution                              | Concentration (M) | Volume (mL) |
|---------------------------------------|-------------------|-------------|
| $\text{Na}_2\text{S}_2\text{O}_3(aq)$ | 0.500             | 10.0        |
| $\text{NaOCl}(aq)$                    | 0.500             | 10.0        |
| $\text{NaOH}(aq)$                     | 0.500             | 10.0        |

The magnitude of the enthalpy change,  $\Delta H_{rxn}^{\circ}$ , in kJ/mol<sub>rxn</sub>, calculated from the results of the second experiment is the same as the result calculated in part (e)(ii). Explain this result.

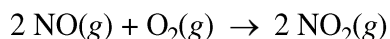
|                                                                                                                                                                                                                                                                                                                                                                                                                                  |                                                 |
|----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|-------------------------------------------------|
| <p>By doubling the volumes, the number of moles of the reactants are doubled, which doubles the amount of energy produced. Therefore the amount of heat per mole will remain the same.</p> <p>OR</p> <p>In the second experiment, <math>\Delta H_{rxn}^{\circ} = \frac{2mc\Delta T}{2n} = \frac{mc\Delta T}{n} = \Delta H_{rxn}^{\circ}</math>.</p> <p>Thus the magnitude is the same as calculated in the first experiment.</p> | <p>1 point is earned for valid explanation.</p> |
|----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|-------------------------------------------------|

Write the balanced net ionic equation for the given reaction.

|                                                                                                                                                         |                                                              |
|---------------------------------------------------------------------------------------------------------------------------------------------------------|--------------------------------------------------------------|
| $\text{S}_3^{2-}(aq) + 4 \text{ OCl}^{-}(aq) + 2 \text{ OH}^{-}(aq) \rightarrow 2 \text{ SO}_4^{2-}(aq) + 4 \text{ Cl}^{-}(aq) + \text{H}_2\text{O}(l)$ | <p>1 point is earned for the correct net ionic equation.</p> |
|---------------------------------------------------------------------------------------------------------------------------------------------------------|--------------------------------------------------------------|

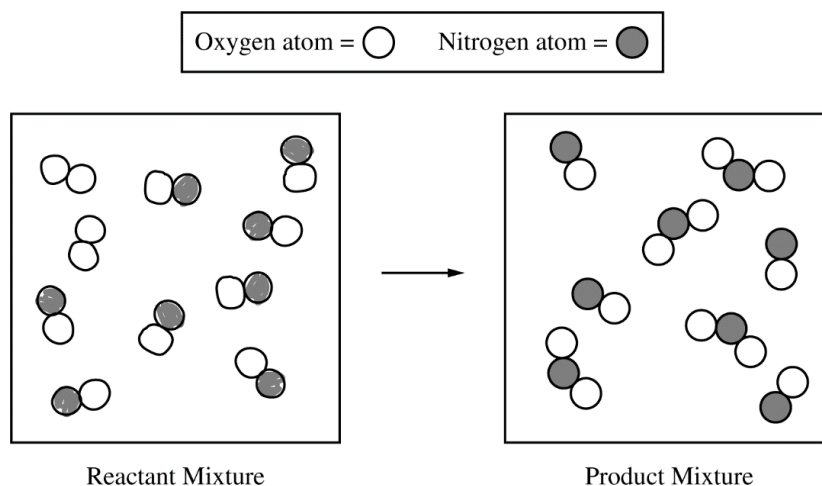
## 2018 SCORING GUIDELINES

## Question 2



A student investigates the reactions of nitrogen oxides. One of the reactions in the investigation requires an equimolar mixture of  $\text{NO}(g)$  and  $\text{NO}_2(g)$ , which the student produces by using the reaction represented above.

- ( The particle-level representation of the equimolar mixture of  $\text{NO}(g)$  and  $\text{NO}_2(g)$  in the flask at the completion of the reaction between  $\text{NO}(g)$  and  $\text{O}_2(g)$  is shown below in the box on the right. In the box below on the left, draw the particle-level representation of the reactant mixture of  $\text{NO}(g)$  and  $\text{O}_2$  would yield the product mixture shown in the box on the right. In your drawing, represent oxygen atoms and nitrogen atoms as indicated below.

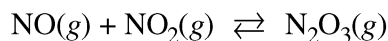


See sample student response above.  
(8 molecules of  $\text{NO}$  and 2 molecules of  $\text{O}_2$ )

1 point is earned for correctly  
representing molecules of  $\text{NO}$  and  $\text{O}$

1 point is earned for correctly  
representing atom conservation.

The student reads in a reference text that  $\text{NO}(g)$  and  $\text{NO}_2(g)$  will react as represented by the equation below. Thermodynamic data for the reaction are given in the table below the equation.



| $\Delta H_{298}^\circ$              | $\Delta S_{298}^\circ$                             | $\Delta G_{298}^\circ$             |
|-------------------------------------|----------------------------------------------------|------------------------------------|
| $-40.4 \text{ kJ/mol}_{\text{rxn}}$ | $-138.5 \text{ J/(K}\cdot\text{mol}_{\text{rxn}})$ | $0.87 \text{ kJ/mol}_{\text{rxn}}$ |

## 2018 SCORING GUIDELINES

## Question 2 (continued)

The student begins with an equimolar mixture of  $\text{NO}(g)$  and  $\text{NO}_2(g)$  in a rigid reaction vessel and the mixture reaches equilibrium at 298 K.

(i) Calculate the value of the equilibrium constant,  $K$ , for the reaction at 298 K.

|                                                                                                                                                                      |                                                      |
|----------------------------------------------------------------------------------------------------------------------------------------------------------------------|------------------------------------------------------|
| $\Delta G^\circ = -RT \ln K$ $K = e^{-\Delta G^\circ / RT}$ $K = e^{-\frac{870 \text{ J/mol}}{(8.314 \text{ J mol}^{-1} \text{ K}^{-1})(298 \text{ K})}}$ $K = 0.70$ | 1 point is earned for a correct calculation of $K$ . |
|----------------------------------------------------------------------------------------------------------------------------------------------------------------------|------------------------------------------------------|

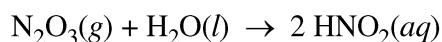
(ii) If both  $P_{\text{NO}}$  and  $P_{\text{NO}_2}$  in the vessel are initially 1.0 atm, will  $P_{\text{N}_2\text{O}_3}$  at equilibrium be equal to 1.0 atm? Justify your answer.

|                                                                                                                                                                                                                                                                               |                                                                                      |
|-------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|--------------------------------------------------------------------------------------|
| <p>No, the pressure will not equal 1.0 atm.</p> <p><math>P_{\text{N}_2\text{O}_3}</math> would only equal 1.0 atm if the reaction goes to completion.</p> <p>The value of <math>K</math> indicates that a substantial amount of reactants will be present at equilibrium.</p> | 1 point is earned for a correct choice and valid justification based on the value of |
|-------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|--------------------------------------------------------------------------------------|

The student hypothesizes that increasing the temperature will increase the amount of  $\text{N}_2\text{O}_3(g)$  in the equilibrium mixture. Indicate whether you agree or disagree with the hypothesis. Justify your answer.

|                                                                                                                                                                                           |                                                                              |
|-------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|------------------------------------------------------------------------------|
| <p>Disagree.</p> <p>Because the reaction is exothermic, increasing the temperature of the reaction will favor the formation of the reactants (according to Le Chatelier's principle).</p> | 1 point is earned for the correct choice <u>and</u> a correct justification. |
|-------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|------------------------------------------------------------------------------|

g) reacts with water to form nitrous acid,  $\text{HNO}_2(aq)$ , a compound involved in the production of acid rain. The reaction is represented below.



## 2018 SCORING GUIDELINES

## Question 2 (continued)

The skeletal structure of the  $\text{HNO}_2$  molecule is shown in the box below.

- (i) Complete the Lewis electron-dot diagram of the  $\text{HNO}_2$  molecule in the box below, including any lone pairs of electrons.

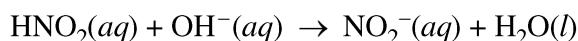


|                                                                                        |                                        |
|----------------------------------------------------------------------------------------|----------------------------------------|
| See sample response above.<br>(Line segments can be used to represent electron pairs.) | 1 point is earned for a valid diagram. |
|----------------------------------------------------------------------------------------|----------------------------------------|

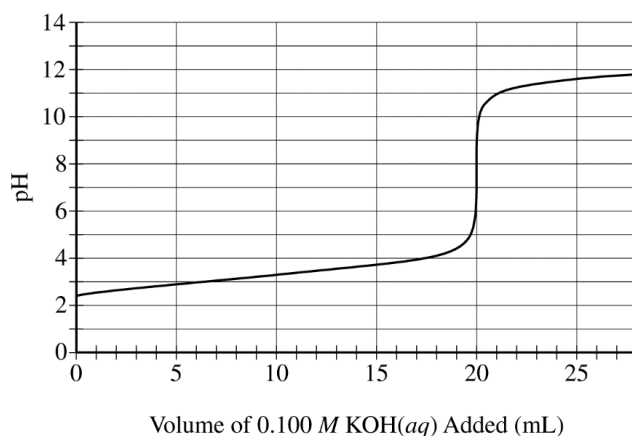
- (ii) Based on your completed diagram above, identify the hybridization of the nitrogen atom in the  $\text{HNO}_2$  molecule.

|        |                                           |
|--------|-------------------------------------------|
| $sp^2$ | 1 point is earned for the correct answer. |
|--------|-------------------------------------------|

To produce an aqueous solution of  $\text{HNO}_2$ , the student bubbles  $\text{N}_2\text{O}_3(g)$  into distilled water. Assume that the reaction goes to completion and that  $\text{HNO}_2$  is the only species produced. To determine the concentration of  $\text{HNO}_2(aq)$  in the resulting solution, the student titrates a 100. mL sample of the solution with 0.100  $\text{KOH}(aq)$ . The neutralization reaction is represented below.



The following titration curve shows the change in pH of the solution during the titration.



## 2018 SCORING GUIDELINES

## Question 2 (continued)

Use the titration curve and the information above to

- (i) determine the initial concentration of the  $\text{HNO}_2(aq)$  solution

|                                                                                                                                                                                                                                                                                                                                       |                                                                                    |
|---------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|------------------------------------------------------------------------------------|
| $\text{mL KOH} \times \frac{0.100 \text{ mol KOH}}{1000 \text{ mL KOH}} = 0.0020 \text{ mol KOH added}$ $\Rightarrow 0.0020 \text{ mol HNO}_2 \text{ in } 100. \text{ mL of solution because the stoichiometry of the neutralization reaction is 1 to 1.}$ $\frac{0.0020 \text{ mol HNO}_2}{0.100 \text{ L}} = 0.020 \text{ M HNO}_2$ | <p>1 point is earned for the correct calculation of the initial concentration.</p> |
|---------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|------------------------------------------------------------------------------------|

- (ii) estimate the value of  $\text{p}K_a$  for  $\text{HNO}_2(aq)$

|                                          |                                                                               |
|------------------------------------------|-------------------------------------------------------------------------------|
| The value of $\text{p}K_a$ is about 3.4. | 1 point is earned for an acceptable estimate for the value of $\text{p}K_a$ . |
|------------------------------------------|-------------------------------------------------------------------------------|

During the titration, after a volume of 15 mL of 0.100 M  $\text{KOH}(aq)$  has been added, which species,  $\text{HNO}_2(aq)$  or  $\text{NO}_2^-(aq)$ , is present at a higher concentration in the solution? Justify your answer.

|                                                                                                                                                   |                                                                                   |
|---------------------------------------------------------------------------------------------------------------------------------------------------|-----------------------------------------------------------------------------------|
| <p><math>(aq)</math></p> <p>The titration is past the half-equivalence point; therefore, there will be more conjugate base present than acid.</p> | <p>1 point is earned for the correct choice <u>and</u> a valid justification.</p> |
|---------------------------------------------------------------------------------------------------------------------------------------------------|-----------------------------------------------------------------------------------|

## 2018 SCORING GUIDELINES

## Question 3

Answer the following questions relating to Fe and its ions,  $\text{Fe}^{2+}$  and  $\text{Fe}^{3+}$ .

Write the ground-state electron configuration of the  $\text{Fe}^{2+}$  ion.

$1s^2 2s^2 2p^6 3s^2 3p^6 3d^6$  OR  $[\text{Ar}] 3d^6$

1 point is earned for a correct electron configuration.

| Ion              | Ionic Radius (pm) |
|------------------|-------------------|
| $\text{Fe}^{2+}$ | 92                |
| $\text{Fe}^{3+}$ | 79                |

The radii of the ions are given in the table above. Using principles of atomic structure, explain why the radius of the  $\text{Fe}^{2+}$  ion is larger than the radius of the  $\text{Fe}^{3+}$  ion.

Both ions have the same nuclear charge; however, the greater number of electrons in the outermost shell of  $\text{Fe}^{2+}$  results in greater electron-electron repulsion within that shell, leading to a larger radius.

1 point is earned for a valid explanation.

$\text{Fe}^{3+}$  ions interact more strongly with water molecules in aqueous solution than  $\text{Fe}^{2+}$  ions do. Give one reason for this stronger interaction, and justify your answer using Coulomb's law.

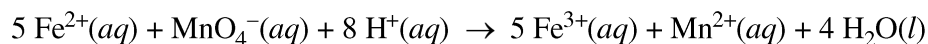
Coulomb's law:  $F \propto \frac{q_1 q_2}{r^2}$  (need not be explicitly stated)

In comparison to the  $\text{Fe}^{2+}$  ion, the  $\text{Fe}^{3+}$  ion has a higher charge.

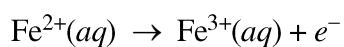
The smaller size of  $\text{Fe}^{3+}$  allows it to get closer to a water molecule.

1 point is earned for a valid explanation.

A student obtains a solution that contains an unknown concentration of  $\text{Fe}^{2+}(aq)$ . To determine the concentration of  $\text{Fe}^{2+}(aq)$  in the solution, the student titrates a sample of the solution with  $\text{MnO}_4^-$  (which converts  $\text{Fe}^{2+}(aq)$  to  $\text{Fe}^{3+}(aq)$ ), as represented by the following equation.



Write the balanced equation for the half-reaction for the oxidation of  $\text{Fe}^{2+}(aq)$  to  $\text{Fe}^{3+}(aq)$ .



1 point is earned for the correct half-reaction.

## 2018 SCORING GUIDELINES

## Question 3 (continued)

The student titrates a 10.0 mL sample of the  $\text{Fe}^{2+}(\text{aq})$  solution. Calculate the value of  $[\text{Fe}^{2+}]$  in solution if it takes 17.48 mL of added  $0.0350\text{ M KMnO}_4(\text{aq})$  to reach the equivalence point of the titration.

|                                                                                                                                                                                                                                                                                                         |                                                                                                                                                                                                      |
|---------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| $17.48\text{ mL} \times \frac{0.0350\text{ mol KMnO}_4}{1000\text{ mL}} = 0.000612\text{ mol KMnO}_4$ $0.000612\text{ mol KMnO}_4 \times \frac{5\text{ mol Fe}^{2+}}{1\text{ mol KMnO}_4} = 0.003059\text{ mol Fe}^{2+}$ $\frac{0.003059\text{ mol Fe}^{2+}}{0.0100\text{ L}} = 0.306\text{ M Fe}^{2+}$ | <p>1 point is earned for calculating the number of moles of <math>\text{KMnO}_4</math> (may be implicit).</p> <p>1 point is earned for the correct concentration of <math>\text{Fe}^{2+}</math>.</p> |
|---------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|

To deliver the 10.0 mL sample of the  $\text{Fe}^{2+}(\text{aq})$  solution in part (e), the student has the choice of using one of the pieces of glassware listed below.

- 25 mL buret
- 25 mL graduated cylinder
- 25 mL beaker
- 25 mL volumetric flask

Explain why the 25 mL volumetric flask would be a poor choice to use for delivering the required volume of the  $\text{Fe}^{2+}(\text{aq})$  solution.

|                                                                      |                                            |
|----------------------------------------------------------------------|--------------------------------------------|
| The volumetric flask is designed to contain only 25.00 mL precisely. | 1 point is earned for a valid explanation. |
|----------------------------------------------------------------------|--------------------------------------------|

## 2018 SCORING GUIDELINES

## Question 3 (continued)

In a separate experiment, the student is given a sample of powdered Fe(s) that contains an inert impurity. The student uses a procedure to oxidize the Fe(s) in the sample to Fe<sub>2</sub>O<sub>3</sub>(s). The student collects the following data during the experiment.

|                                                     |         |
|-----------------------------------------------------|---------|
| Mass of Fe(s) with inert impurity                   | 6.724 g |
| Mass of Fe <sub>2</sub> O <sub>3</sub> (s) produced | 7.531 g |

Calculate the number of moles of Fe in the Fe<sub>2</sub>O<sub>3</sub>(s) produced.

|                                                                                                                                                                                                                                                                              |                                            |
|------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|--------------------------------------------|
| $7.531 \text{ g Fe}_2\text{O}_3 \times \frac{1 \text{ mol Fe}_2\text{O}_3}{159.70 \text{ g Fe}_2\text{O}_3} = 0.04716 \text{ mol Fe}_2\text{O}_3$ $0.04716 \text{ mol Fe}_2\text{O}_3 \times \frac{2 \text{ mol Fe}}{1 \text{ mol Fe}_2\text{O}_3} = 0.09431 \text{ mol Fe}$ | 1 point is earned for correct calculation. |
|------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|--------------------------------------------|

Calculate the percent by mass of Fe in the original sample of powdered Fe(s) with the inert impurity.

|                                                                                                                                                                        |                                                                                                |
|------------------------------------------------------------------------------------------------------------------------------------------------------------------------|------------------------------------------------------------------------------------------------|
| $0.09431 \text{ mol Fe} \times \frac{55.85 \text{ g Fe}}{1 \text{ mol}} = 5.267 \text{ g Fe}$ $\frac{5.267 \text{ g Fe}}{6.724 \text{ g sample}} \times 100 = 78.33\%$ | 1 point is earned for correct calculation of the mass percent based on the answer to part (g). |
|------------------------------------------------------------------------------------------------------------------------------------------------------------------------|------------------------------------------------------------------------------------------------|

If the oxidation of the Fe(s) in the original sample was incomplete so that some of the 7.531 g of product was FeO(s) instead of Fe<sub>2</sub>O<sub>3</sub>(s), would the calculated mass percent of Fe(s) in the original sample be higher, lower, or the same as the actual mass percent of Fe(s)? Justify your answer.

|                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                  |                                                                   |
|------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|-------------------------------------------------------------------|
| <p>The calculated mass percent of Fe would be lower than the actual mass percent of Fe.</p> <p>A sample that contains any FeO (rather than Fe<sub>2</sub>O<sub>3</sub>) will have a lower <u>actual</u> mass percent of Fe than a completely oxidized sample would have. Therefore, when the moles of Fe are calculated (assuming all the mass of the sample is Fe<sub>2</sub>O<sub>3</sub>) the <u>calculated</u> number of moles of Fe, and hence the <u>calculated</u> mass percent of Fe, will be lower.</p> | 1 point is earned for the correct answer and a valid explanation. |
|------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|-------------------------------------------------------------------|

## 2018 SCORING GUIDELINES

## Question 4

Sulfur atom =  Carbon atom =  Oxygen atom = 

| Compound        | Molecular Structure                                                               | Boiling Point at 1 atm (K) |
|-----------------|-----------------------------------------------------------------------------------|----------------------------|
| CS <sub>2</sub> |  | 319                        |
| COS             |  | 223                        |

The table above gives the molecular structures and boiling points for the compounds CS<sub>2</sub> and COS.

In terms of the types and relative strengths of all the intermolecular forces in each compound, explain why the boiling point of CS<sub>2</sub>(*l*) is higher than that of COS(*l*).

has only London dispersion forces, while COS has London dispersion forces and dipole-dipole forces.

The London dispersion forces in CS<sub>2</sub> are stronger than the combination of London dispersion forces and dipole-dipole forces in COS.

1 point is earned for correctly identifying all of the intermolecular forces in **both** molecules.

1 point is earned for a valid explanation.

A 10.0 g sample of CS<sub>2</sub>(*l*) is put in an evacuated 5.0 L rigid container. The container is sealed and heated to 325 K, at which temperature all of the CS<sub>2</sub>(*l*) has vaporized. What is the pressure in the container once all of the CS<sub>2</sub>(*l*) has vaporized?

$$10.0 \text{ g CS}_2 \times \frac{1 \text{ mol CS}_2}{76.13 \text{ g CS}_2} = 0.131 \text{ mol CS}_2$$

$$: \frac{nRT}{V} = \frac{(0.131 \text{ mol})(0.08206 \text{ L atm mol}^{-1} \text{ K}^{-1})(325 \text{ K})}{5.0 \text{ L}}$$

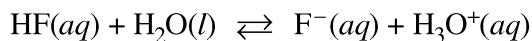
$$= 0.70 \text{ atm}$$

1 point is earned for the correct number of moles of

1 point is earned for the correct calculation of pressure with appropriate units.

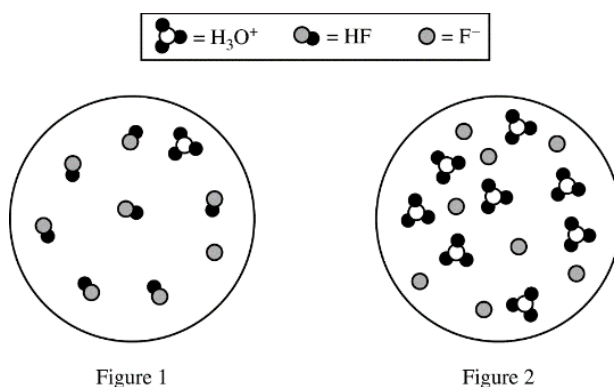
## 2018 SCORING GUIDELINES

## Question 5



The ionization of  $\text{HF}(aq)$  in water is represented by the equation above. In a  $0.0350\text{ M}$   $\text{HF}(aq)$  solution, the percent ionization of  $\text{HF}$  is 13.0 percent.

Two particulate representations of the ionization of  $\text{HF}$  molecules in the  $0.0350\text{ M}$   $\text{HF}(aq)$  solution shown below in Figure 1 and Figure 2. Water molecules are not shown. Explain why the representation of the ionization of  $\text{HF}$  molecules in water in Figure 1 is more accurate than the representation in Figure 2. (The key below identifies the particles in the representations.)



## 2018 SCORING GUIDELINES

## Question 5 (continued)

If 50.0 mL of distilled water is added to 50.0 mL of 0.035  $M$  HF(aq), will the percent ionization HF(aq) in the solution increase, decrease, or remain the same? Justify your answer with an explanation or calculation.

The percent ionization of HF in the solution would increase.

Doubling the volume of the solution decreases the initial concentration of each species by one-half; therefore,

$$\frac{(\frac{1}{2}[\text{H}_3\text{O}^+]_i)(\frac{1}{2}[\text{F}^-]_i)}{\frac{1}{2}[\text{HF}]_i} = \frac{1}{2}K_a \Rightarrow Q < K_a.$$

Consequently the equilibrium position will shift toward the products and increase the percent ionization.

New volume = twice original volume, thus new  $[\text{HF}]_i = \frac{0.035}{2} = 0.0175 M$

$$= \frac{[\text{H}_3\text{O}^+][\text{F}^-]}{[\text{HF}]} = 6.81 \times 10^{-4} \text{ (value from part (b))}$$

Let  $[\text{H}_3\text{O}^+] = [\text{F}^-] = x$

$$\text{Then } 6.81 \times 10^{-4} = \frac{(x)(x)}{(0.0175 - x)} \approx \frac{x^2}{(0.0175)} \Rightarrow x \approx 0.00345 M$$

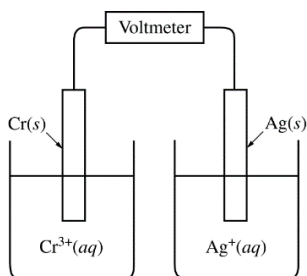
$$\text{Percent ionization} = \frac{0.00345 M}{0.0175 M} \times 100 = 20.0\%$$

$\% > 13.0\%$ ; therefore, the percent ionization increases.

1 point is earned for correct answer valid explanation or calculation.

## 2018 SCORING GUIDELINES

## Question 6



A student sets up a galvanic cell at 298 K that has an electrode of Ag(s) immersed in a 1.0 M solution of  $\text{Ag}^+(aq)$  and an electrode of Cr(s) immersed in a 1.0 M solution of  $\text{Cr}^{3+}(aq)$ , as shown in the diagram above.

The student measures the voltage of the cell shown above and discovers that it is zero. Identify the missing component of the cell, and explain its importance for obtaining a nonzero voltage.

A salt bridge is missing. The salt bridge allows for the migration of ions to maintain charge balance in each half-cell.

1 point is earned for the correct answer and a valid explanation.

| Half-Reaction                                         | $E^\circ$ (V) |
|-------------------------------------------------------|---------------|
| $\text{Ag}^+(aq) + e^- \rightarrow \text{Ag}(s)$      | + 0.80        |
| $\text{Cr}^{3+}(aq) + 3 e^- \rightarrow \text{Cr}(s)$ | ?             |

The student adds the missing component to the cell and measures  $E_{\text{cell}}^\circ$  to be +1.54 V. As the cell operates,  $\text{Ag}^+$  ions are reduced. Use this information and the information in the table above to do the following.

(i) Calculate the value of  $E^\circ$  for the half-reaction  $\text{Cr}^{3+}(aq) + 3 e^- \rightarrow \text{Cr}(s)$ .

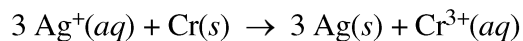
$$E_{\text{cell}}^\circ = E_{\text{red}}^\circ(\text{cathode}) - E_{\text{red}}^\circ(\text{anode})$$

$$+1.54 \text{ V} = +0.80 \text{ V} - x$$

$$= +0.80 \text{ V} - (+1.54 \text{ V}) = -0.74 \text{ V}$$

1 point is earned for a correct calculation of  $E_{\text{red}}^\circ$ .

(ii) Write the balanced net-ionic equation for the overall reaction that occurs as the cell operates.



1 point is earned for the correctly balanced equation.

## 2018 SCORING GUIDELINES

## Question 6 (continued)

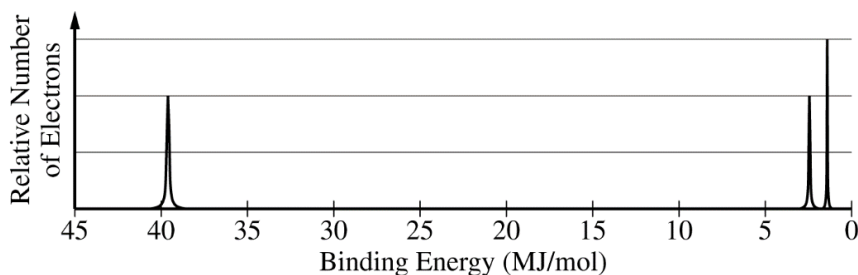
(iii) Calculate the value of  $\Delta G^\circ$  for the overall cell reaction in  $\text{J/mol}_{\text{rxn}}$ .

$$\begin{aligned}\Delta G^\circ &= -nFE^\circ = -\left(\frac{3 \text{ mol } e^-}{1 \text{ mol}_{\text{rxn}}}\right)\left(96,485 \frac{\text{C}}{\text{mol } e^-}\right)\left(1.54 \frac{\text{J}}{\text{C}}\right) \\ &= -4.46 \times 10^5 \text{ J/mol}_{\text{rxn}}\end{aligned}$$

1 point is earned for the correct calculation of the value of  $\Delta$

## 2018 SCORING GUIDELINES

## Question 7



The complete photoelectron spectrum of an element is represented above.

Identify the element.

|                             |                                                          |
|-----------------------------|----------------------------------------------------------|
| The element is nitrogen, N. | 1 point is earned for correctly identifying the element. |
|-----------------------------|----------------------------------------------------------|

A radioactive isotope of the element decays with a half-life of 10. minutes.

Calculate the value of the rate constant,  $k$ , for the radioactive decay. Include units with your answer.

|                                                                                      |                                                                                                           |
|--------------------------------------------------------------------------------------|-----------------------------------------------------------------------------------------------------------|
| $k = \frac{0.693}{t_{1/2}} = \frac{0.693}{10. \text{ min}} = 0.069 \text{ min}^{-1}$ | <p>1 point is earned for the correct numerical answer.</p> <p>1 point is earned for the correct unit.</p> |
|--------------------------------------------------------------------------------------|-----------------------------------------------------------------------------------------------------------|

If 64 atoms of the radioactive isotope are originally present in a sample, what is the expected amount of time that will pass until only one atom of the isotope remains? Show how you arrived at your answer.

|                                                                                                                                                                                                                                                                                                                                                                                                           |                                                                     |
|-----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|---------------------------------------------------------------------|
| <p> <math>64 \rightarrow 32 \rightarrow 16 \rightarrow 8 \rightarrow 4 \rightarrow 2 \rightarrow 1</math><br/>         6 half-lives are required.<br/> <math>6 \times 10. \text{ min} = 60. \text{ min}</math> </p> <p style="text-align: center;"><b>OR</b></p> <p> <math>\ln[A]_t - \ln[A]_0 = -kt</math><br/> <math>t = \frac{\ln(1) - \ln(64)}{-0.069 \text{ min}^{-1}} = 60. \text{ min}</math> </p> | 1 point is earned for the correct answer <u>and</u> a valid method. |
|-----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|---------------------------------------------------------------------|

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# AP<sup>®</sup> Chemistry

## 2014 Scoring Guidelines

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## 4 SCORING GUIDELINES

Question 1  
(10 points)

|                                                        |         |
|--------------------------------------------------------|---------|
| Mass of KI tablet                                      | 0.425 g |
| Mass of thoroughly dried filter paper                  | 1.462 g |
| Mass of filter paper + precipitate after first drying  | 1.775 g |
| Mass of filter paper + precipitate after second drying | 1.699 g |
| Mass of filter paper + precipitate after third drying  | 1.698 g |

A student is given the task of determining the  $\text{I}^-$  content of tablets that contain KI and an inert, water-soluble sugar as a filler. A tablet is dissolved in 50.0 mL of distilled water, and an excess of  $0.20\text{ M Pb(NO}_3)_2(aq)$  is added to the solution. A yellow precipitate forms, which is then filtered, washed, and dried. The data from the experiment are shown in the table above.

(a) For the chemical reaction that occurs when the precipitate forms,

(i) write a balanced, net-ionic equation for the reaction, and

|                                                         |                                                      |
|---------------------------------------------------------|------------------------------------------------------|
| $\text{Pb}^{2+} + 2\text{I}^- \rightarrow \text{PbI}_2$ | 1 point is earned for a balanced net-ionic equation. |
|---------------------------------------------------------|------------------------------------------------------|

(ii) explain why the reaction is best represented by a net-ionic equation.

|                                                                                                                                                                                                                         |                                            |
|-------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|--------------------------------------------|
| The net-ionic equation shows the formation of the $\text{PbI}_2(s)$ from $\text{Pb}^{2+}(aq)$ and $\text{I}^-(aq)$ ions, omitting the non-reacting species (spectator ions), $\text{K}^+(aq)$ and $\text{NO}_3^-(aq)$ . | 1 point is earned for a valid explanation. |
|-------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|--------------------------------------------|

(b) Explain the purpose of drying and weighing the filter paper with the precipitate three times.

|                                                                                                                                     |                                            |
|-------------------------------------------------------------------------------------------------------------------------------------|--------------------------------------------|
| The filter paper and precipitate must be dried several times (to a constant mass) to ensure that all the water has been driven off. | 1 point is earned for a valid explanation. |
|-------------------------------------------------------------------------------------------------------------------------------------|--------------------------------------------|

(c) In the filtrate solution, is  $[\text{K}^+]$  greater than, less than, or equal to  $[\text{NO}_3^-]$ ? Justify your answer.

|                                                                                                                                                     |                                                                      |
|-----------------------------------------------------------------------------------------------------------------------------------------------------|----------------------------------------------------------------------|
| $[\text{K}^+]$ is less than $[\text{NO}_3^-]$ because the source of the $\text{NO}_3^-$ , the $0.20\text{ M Pb(NO}_3)_2(aq)$ , was added in excess. | 1 point is earned for a correct comparison with a valid explanation. |
|-----------------------------------------------------------------------------------------------------------------------------------------------------|----------------------------------------------------------------------|

## 4 SCORING GUIDELINES

## Question 1 (continued)

(d) Calculate the number of moles of precipitate that is produced in the experiment.

|                                                                                                                                                                                            |                                                                                     |
|--------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|-------------------------------------------------------------------------------------|
| $1.698 \text{ g} - 1.462 \text{ g} = 0.236 \text{ g PbI}_2(s)$<br>$0.236 \text{ g PbI}_2 \times \frac{1 \text{ mol PbI}_2}{461.0 \text{ g PbI}_2} = 5.12 \times 10^{-4} \text{ mol PbI}_2$ | 1 point is earned for the correct number of moles of $\text{PbI}_2(s)$ precipitate. |
|--------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|-------------------------------------------------------------------------------------|

(e) Calculate the mass percent of  $\text{I}^-$  in the tablet.

|                                                                                                                                                                                                                                                                                                                                                                                             |                                                                                                                                                                                                               |
|---------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|---------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| $5.12 \times 10^{-4} \text{ mol PbI}_2 \times \frac{2 \text{ mol I}^-}{1 \text{ mol PbI}_2} = 1.02 \times 10^{-3} \text{ mol I}^-$<br>$1.02 \times 10^{-3} \text{ mol I}^- \times \frac{126.91 \text{ g I}^-}{1 \text{ mol I}^-} = 0.130 \text{ g I}^- \text{ in one tablet}$<br>$\frac{0.130 \text{ g I}^-}{0.425 \text{ g KI tablet}} = 0.306 = 30.6\% \text{ I}^- \text{ per KI tablet}$ | <p>1 point is earned for determining the number of moles of <math>\text{I}^-</math> in one tablet.</p> <p>1 point is earned for calculating the mass percent of <math>\text{I}^-</math> in the KI tablet.</p> |
|---------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|---------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|

(f) In another trial, the student dissolves a tablet in 55.0 mL of water instead of 50.0 mL of water. Predict whether the experimentally determined mass percent of  $\text{I}^-$  will be greater than, less than, or equal to the amount calculated in part (e). Justify your answer.

|                                                                                                                                                                                                                                                                    |                                                                      |
|--------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|----------------------------------------------------------------------|
| The mass percent of $\text{I}^-$ will be the same. $\text{Pb}^{2+}(aq)$ was added in excess, ensuring that essentially no $\text{I}^-$ remained in solution. The additional water is removed by filtration and drying, leaving the same mass of dried precipitate. | 1 point is earned for correct comparison with a valid justification. |
|--------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|----------------------------------------------------------------------|

(g) A student in another lab also wants to determine the  $\text{I}^-$  content of a KI tablet but does not have access to  $\text{Pb}(\text{NO}_3)_2$ . However, the student does have access to  $0.20 \text{ M AgNO}_3$ , which reacts with  $\text{I}^-(aq)$  to produce  $\text{AgI}(s)$ . The value of  $K_{sp}$  for  $\text{AgI}$  is  $8.5 \times 10^{-17}$ .

(i) Will the substitution of  $\text{AgNO}_3$  for  $\text{Pb}(\text{NO}_3)_2$  result in the precipitation of the  $\text{I}^-$  ion from solution? Justify your answer.

|                                                                                                                                                                                                               |                                                                      |
|---------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|----------------------------------------------------------------------|
| Yes. Addition of an excess of $0.20 \text{ M AgNO}_3(aq)$ will precipitate all of the $\text{I}^-$ ion present in the solution because $\text{AgI}$ is insoluble, as evidenced by its low value of $K_{sp}$ . | 1 point is earned for the correct answer with a valid justification. |
|---------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|----------------------------------------------------------------------|

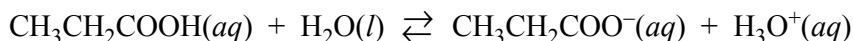
(ii) The student only has access to one KI tablet and a balance that can measure to the nearest 0.01 g. Will the student be able to determine the mass of  $\text{AgI}$  produced to three significant figures? Justify your answer.

**4 SCORING GUIDELINES****Question 1 (continued)**

No. If masses can be measured to  $\pm 0.01$  g, then the mass of the dry  $\text{AgI}(s)$  precipitate (which is less than 1 g) will be known to only two significant figures.

1 point is earned for a correct answer with a valid justification.

## 2014 SCORING GUIDELINES

Question  
(10 points)

Propanoic acid,  $\text{CH}_3\text{CH}_2\text{COOH}$ , is a carboxylic acid that reacts with water according to the equation above. At  $25^\circ\text{C}$  the pH of a 50.0 mL sample of 0.20 M  $\text{CH}_3\text{CH}_2\text{COOH}$  is 2.79.

- (a) Identify a Brønsted-Lowry conjugate acid-base pair in the reaction. Clearly label which is the acid and which is the base.

|                                                                                                                                                                                                                                                                               |                                                                                                                                                                      |
|-------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|----------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| $\text{CH}_3\text{CH}_2\text{COOH}$ and $\text{CH}_3\text{CH}_2\text{COO}^-$<br><i>acid</i> <span style="margin-left: 100px;"><i>base</i></span><br>OR<br>$\text{H}_3\text{O}^+$ and $\text{H}_2\text{O}$<br><i>acid</i> <span style="margin-left: 100px;"><i>base</i></span> | 1 point is earned for writing (or naming) either of the Brønsted-Lowry conjugate acid-base pairs with a clear indication of which is the acid and which is the base. |
|-------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|----------------------------------------------------------------------------------------------------------------------------------------------------------------------|

- (b) Determine the value of  $K_a$  for propanoic acid at  $25^\circ\text{C}$ .

|                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                       |                                                                                                                                                                                                                                                                                                   |
|-------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|---------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| $[\text{H}_3\text{O}^+] = 10^{-\text{pH}} = 10^{-2.79} = 1.6 \times 10^{-3} \text{ M}$<br><br>$[\text{CH}_3\text{CH}_2\text{COO}^-] = [\text{H}_3\text{O}^+]$<br>AND<br>$[\text{CH}_3\text{CH}_2\text{COOH}] = 0.20 \text{ M} - [\text{H}_3\text{O}^+]$ , OR $[\text{CH}_3\text{CH}_2\text{COOH}] \approx 0.20 \text{ M}$<br>(state or assume that $[\text{H}_3\text{O}^+] \ll 0.20 \text{ M}$ )<br><br>$K_a = \frac{[\text{CH}_3\text{CH}_2\text{COO}^-][\text{H}_3\text{O}^+]}{[\text{CH}_3\text{CH}_2\text{COOH}]} = \frac{(1.6 \times 10^{-3} \text{ M})^2}{0.20 \text{ M}} = 1.3 \times 10^{-5}$ | 1 point is earned for correctly solving for $[\text{H}_3\text{O}^+]$ .<br><br>1 point is earned for the $K_a$ expression for propanoic acid<br>OR<br>1 point is earned for substituting values into the $K_a$ expression.<br><br>1 point is earned for correctly solving for the value of $K_a$ . |
|-------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|---------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|

- (c) For each of the following statements, determine whether the statement is true or false. In each case, explain the reasoning that supports your answer.

- (i) The pH of a solution prepared by mixing the 50.0 mL sample of 0.20 M  $\text{CH}_3\text{CH}_2\text{COOH}$  with a 50.0 mL sample of 0.20 M NaOH is 7.00.

|                                                                                                                                                                                                                                                                                 |                                                                                                  |
|---------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|--------------------------------------------------------------------------------------------------|
| False. The conjugate base of a weak acid undergoes hydrolysis (see equation below) at equivalence to form a solution with a $\text{pH} > 7$ .<br>$(\text{CH}_3\text{CH}_2\text{COO}^- + \text{H}_2\text{O} \rightleftharpoons \text{CH}_3\text{CH}_2\text{COOH} + \text{OH}^-)$ | 1 point is earned for noting that the statement is false AND providing a supporting explanation. |
|---------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|--------------------------------------------------------------------------------------------------|

## 2014 SCORING GUIDELINES

## Question 2 (continued)

- (ii) If the pH of a hydrochloric acid solution is the same as the pH of a propanoic acid solution, then the molar concentration of the hydrochloric acid solution must be less than the molar concentration of the propanoic acid solution.

|                                                                                                                                                                                              |                                                                                                 |
|----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|-------------------------------------------------------------------------------------------------|
| True. HCl is a strong acid that ionizes completely. Fewer moles of HCl are needed to produce the same $[\text{H}_3\text{O}^+]$ as the propanoic acid solution, which only partially ionizes. | 1 point is earned for noting that the statement is true and providing a supporting explanation. |
|----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|-------------------------------------------------------------------------------------------------|

A student is given the task of determining the concentration of a propanoic acid solution of unknown concentration. A 0.173 M NaOH solution is available to use as the titrant. The student uses a 25.00 mL volumetric pipet to deliver the propanoic acid solution to a clean, dry flask. After adding an appropriate indicator to the flask, the student titrates the solution with the 0.173 M NaOH, reaching the end point after 20.52 mL of the base solution has been added.

- (d) Calculate the molarity of the propanoic acid solution.

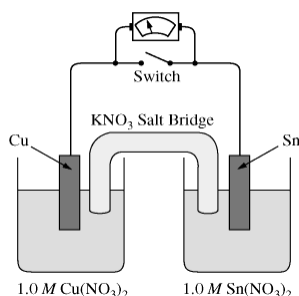
|                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                     |                                                                                                                                                                                  |
|---------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| <p>Let <math>x</math> = moles of propanoic acid</p> <p>then <math>x = (0.02052 \text{ L NaOH}) \times \frac{0.173 \text{ mol NaOH}}{1 \text{ L NaOH}} \times \frac{1 \text{ mol acid}}{1 \text{ mol NaOH}}</math></p> <p><math>= 3.55 \times 10^{-3} \text{ mol propanoic acid}</math></p> <p><math>\frac{3.55 \times 10^{-3} \text{ mol acid}}{0.02500 \text{ L acid}} = 0.142 \text{ M}</math></p> <p>OR</p> <p>Since <math>\text{CH}_3\text{CH}_2\text{COOH}</math> is monoprotic and, at the equivalence point, moles <math>\text{H}^+ = \text{moles OH}^-</math>, then</p> <p><math>M_A V_A = M_B V_B</math></p> <p><math>M_A = \frac{M_B V_B}{V_A} = \frac{(0.173 \text{ M NaOH})(20.52 \text{ mL NaOH})}{25.00 \text{ mL acid}} = 0.142 \text{ M}</math></p> | <p>1 point is earned for correctly calculating the number of moles of acid that reacted at the equivalence point.</p> <p>1 point is earned for the correct molarity of acid.</p> |
|---------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|

- (e) The student is asked to redesign the experiment to determine the concentration of a butanoic acid solution instead of a propanoic acid solution. For butanoic acid the value of  $\text{p}K_a$  is 4.83. The student claims that a different indicator will be required to determine the equivalence point of the titration accurately. Based on your response to part (b), do you agree with the student's claim? Justify your answer.

**2014 SCORING GUIDELINES****Question 2 (continued)**

|                                                                                                                                                                                                                                                                                                                                                                                                                          |                                                                                                                                                                                                                                                                                                                                             |
|--------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|---------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| <p><u>Disagree</u> with the student's claim</p> <p>From part (b) above, <math>pK_a</math> for propanoic acid is <math>\log(1.3 \times 10^{-5}) = 4.89</math>. Because 4.83 is so close to 4.89, the pH at the equivalence point in the titration of butanoic acid should be close enough to the pH in the titration of propanoic acid to make the original indicator appropriate for the titration of butanoic acid.</p> | <p>1 point is earned for disagreeing with the student's claim and making a valid justification using <math>pK_a</math>, <math>K_a</math>, or pH arguments.</p> <p>1 point is earned for numerically comparing either: the two <math>pK_a</math> values, the two <math>K_a</math> values, or the two pH values at the equivalence point.</p> |
|--------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|---------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|

## SCORING GUIDELINES

Question  
(10 points)

A student is given a standard galvanic cell, represented above, that has a Cu electrode and a Sn electrode. As current flows through the cell, the student determines that the Cu electrode increases in mass and the Sn electrode decreases in mass.

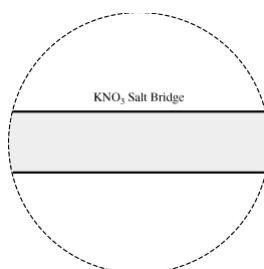
- (a) Identify the electrode at which oxidation is occurring. Explain your reasoning based on the student's observations.

|                                                                                                                                                                                                                                                                                                                           |                                                                     |
|---------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|---------------------------------------------------------------------|
| <p>Since the Sn electrode is losing mass, Sn atoms must be forming <math>\text{Sn}^{2+}(\text{aq})</math>. This process is oxidation.</p> <p>OR</p> <p>because the cell operates, <math>E^\circ</math> must be positive and, based on the <math>E^\circ</math> values from the table, it must be Sn that is oxidized.</p> | <p>1 point is earned for the correct answer with justification.</p> |
|---------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|---------------------------------------------------------------------|

- (b) As the mass of the Sn electrode decreases, where does the mass go?

|                                                                                                       |                                                  |
|-------------------------------------------------------------------------------------------------------|--------------------------------------------------|
| <p>The atoms on the Sn electrode are going into the solution as <math>\text{Sn}^{2+}</math> ions.</p> | <p>1 point is earned for the correct answer.</p> |
|-------------------------------------------------------------------------------------------------------|--------------------------------------------------|

- (c) In the expanded view of the center portion of the salt bridge shown in the diagram below, draw and label a particle view of what occurs in the salt bridge as the cell begins to operate. Omit solvent molecules and use arrows to show the movement of particles.



|                                                                                                                                                                                                         |                                                                                                                                                                                                                                                                 |
|---------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|-----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| <p>The response should show at least one <math>\text{K}^+</math> ion moving toward the Cu compartment on the left and at least one <math>\text{NO}_3^-</math> ion moving in the opposite direction.</p> | <p>1 point is earned for correct representation of both <math>\text{K}^+</math> and <math>\text{NO}_3^-</math> ions. (Including free electrons loses this point.)</p> <p>1 point is earned for correctly indicating the direction of movement of both ions.</p> |
|---------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|-----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|

## SCORING GUIDELINES

## Question 3 (continued)

(d) A nonstandard cell is made by replacing the 1.0 *M* solutions of  $\text{Cu}(\text{NO}_3)_2$  and  $\text{Sn}(\text{NO}_3)_2$  in the standard cell with 0.50 *M* solutions of  $\text{Cu}(\text{NO}_3)_2$  and  $\text{Sn}(\text{NO}_3)_2$ . The volumes of solutions in the nonstandard cell are identical to those in the standard cell.

(i) Is the cell potential of the nonstandard cell greater than, less than, or equal to the cell potential of the standard cell? Justify your answer.

|                                                                                                                                                                                               |                                                              |
|-----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|--------------------------------------------------------------|
| It is the same. In the cell reaction $Q = \frac{[\text{Sn}^{2+}]}{[\text{Cu}^{2+}]}$ , and the concentrations of $\text{Sn}^{2+}$ and $\text{Cu}^{2+}$ are equal to each other in both cases. | 1 point is earned for the correct answer with justification. |
|-----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|--------------------------------------------------------------|

(ii) Both the standard and nonstandard cells can be used to power an electronic device. Would the nonstandard cell power the device for the same time, a longer time, or a shorter time as compared with the standard cell? Justify your answer.

|                                                                                                                                                                                                                                                                                                                                           |                                                              |
|-------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|--------------------------------------------------------------|
| <p>The nonstandard cell would power the device for a shorter time because the supply of <math>\text{Cu}^{2+}</math> ions will be exhausted more quickly.</p> <p style="text-align: center;">OR</p> <p>The nonstandard cell would power the device for a shorter time because the reaction will reach <math>E = 0</math> more quickly.</p> | 1 point is earned for the correct answer with justification. |
|-------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|--------------------------------------------------------------|

(e) In another experiment, the student places a new Sn electrode into a fresh solution of 1.0 *M*  $\text{Cu}(\text{NO}_3)_2$ .

| Half-Reaction                                       | $E^\circ$ (V) |
|-----------------------------------------------------|---------------|
| $\text{Cu}^+ + e^- \rightarrow \text{Cu}(s)$        | 0.52          |
| $\text{Cu}^{2+} + 2 e^- \rightarrow \text{Cu}(s)$   | 0.34          |
| $\text{Sn}^{4+} + 2 e^- \rightarrow \text{Sn}^{2+}$ | 0.15          |
| $\text{Sn}^{2+} + 2 e^- \rightarrow \text{Sn}(s)$   | -0.14         |

(i) Using information from the table above, write a net-ionic equation for the reaction between the Sn electrode and the  $\text{Cu}(\text{NO}_3)_2$  solution that would be thermodynamically favorable. Justify that the reaction is thermodynamically favorable.

## SCORING GUIDELINES

## Question 3 (continued)

|                                                                                                                                                                                                                                                                                                                                                                                                                                                                  |                                                                                                                                                     |
|------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|-----------------------------------------------------------------------------------------------------------------------------------------------------|
| $\text{Cu}^{2+}(\text{aq}) + \text{Sn}(\text{s}) \rightarrow \text{Cu}(\text{s}) + \text{Sn}^{2+}(\text{aq})$ <p><math>E^\circ</math> is positive (<math>0.34 \text{ V} + 0.14 \text{ V} = 0.48 \text{ V}</math>), therefore the reaction is thermodynamically favorable.</p> <p>OR</p> <p>The cell observations from earlier parts of the question are evidence that the Sn is oxidized and Cu is reduced, therefore <math>E^\circ</math> must be positive.</p> | <p>1 point is earned for the correct net-ionic equation.</p> <p>1 point is earned for a correct justification (unit not needed in calculation).</p> |
|------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|-----------------------------------------------------------------------------------------------------------------------------------------------------|

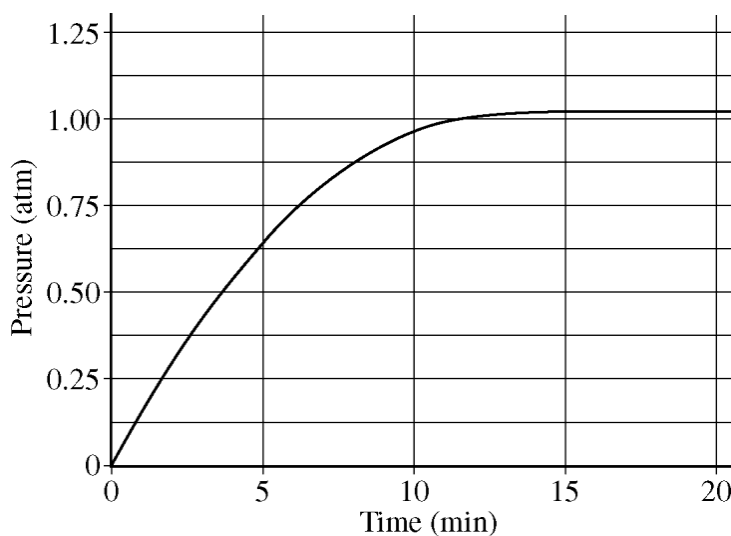
(ii) Calculate the value of  $\Delta G^\circ$  for the reaction. Include units with your answer.

|                                                                                                                                                                                                                                                                    |                                                                                                                          |
|--------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|--------------------------------------------------------------------------------------------------------------------------|
| $\Delta G^\circ = -nFE^\circ$ $\Delta G^\circ = -\frac{2 \text{ mol } e^-}{\text{mol}_{\text{rxn}}} \times \frac{96,485 \text{ C}}{\text{mol } e^-} \times \frac{0.48 \text{ J}}{\text{C}} = -93,000 \text{ J/mol}_{\text{rxn}} = -93 \text{ kJ/mol}_{\text{rxn}}$ | <p>1 point is earned for the correct number of electrons.</p> <p>1 point is earned for the correct answer with unit.</p> |
|--------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|--------------------------------------------------------------------------------------------------------------------------|

## SCORING GUIDELINES

Question  
(4 points)

When heated, calcium carbonate decomposes according to the equation above. In a study of the decomposition of calcium carbonate, a student added a 50.0 g sample of powdered  $\text{CaCO}_3(s)$  to a 1.00 L rigid container. The student sealed the container, pumped out all the gases, then heated the container in an oven at 1100 K. As the container was heated, the total pressure of the  $\text{CO}_2(g)$  in the container was measured over time. The data are plotted in the graph below.



The student repeated the experiment, but this time the student used a 100.0 g sample of powdered  $\text{CaCO}_3(s)$ . In this experiment, the final pressure in the container was 1.04 atm, which was the same final pressure as in the first experiment.

- (a) Calculate the number of moles of  $\text{CO}_2(g)$  present in the container after 20 minutes of heating.

$$PV = nRT$$

$$\frac{PV}{RT} = n = \frac{(1.04 \text{ atm})(1.00 \text{ L})}{(0.0821 \frac{\text{L atm}}{\text{mol K}})(1100 \text{ K})} = 0.0115 \text{ mol CO}_2$$

1 point is earned for the proper setup using the ideal gas law and an answer that is consistent with the setup.

## SCORING GUIDELINES

## Question continued)

- (b) The student claimed that the final pressure in the container in each experiment became constant because all of the  $\text{CaCO}_3(s)$  had decomposed. Based on the data in the experiments, do you agree with this claim? Explain.

|                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                  |                                                                                                                                                                                  |
|------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| <p>Do not agree with claim</p> <p>Explanation I: In experiment 1, the moles of <math>\text{CaCO}_3 = 50.0 \text{ g}/100.09 \text{ g/mol} = 0.500 \text{ mol CaCO}_3</math>. If the reaction had gone to completion, 0.500 mol of <math>\text{CO}_2</math> would have been produced. From part (a) only 0.0115 mol was produced. Hence, the student's claim was false.</p> <p>Explanation II: The two different experiments (one with 50.0 g of <math>\text{CaCO}_3</math> and one with 100.0 g of <math>\text{CaCO}_3</math>) reached the same constant, final pressure of 1.04 atm. Since increasing the amount of reactant did not produce more product, there is no way that all of the <math>\text{CaCO}_3</math> reacted. Instead, an equilibrium condition has been achieved and there must be some solid <math>\text{CaCO}_3</math> in the container.</p> | <p>1 point is earned for disagreement with the claim <u>and</u> for a correct justification using stoichiometry or a discussion of the creation of an equilibrium condition.</p> |
|------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|

- (c) After 20 minutes some  $\text{CO}_2(g)$  was injected into the container, initially raising the pressure to 1.5 atm. Would the final pressure inside the container be less than, greater than, or equal to 1.04 atm? Explain your reasoning.

|                                                                                                                                                                                                                                                                                                                           |                                                                     |
|---------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|---------------------------------------------------------------------|
| <p>The final pressure would be equal to 1.04 atm. Equilibrium was reached in both experiments; the equilibrium pressure at this temperature is 1.04 atm. As the reaction shifts toward the reactant, the amount of <math>\text{CO}_2(g)</math> in the container will decrease until the pressure returns to 1.04 atm.</p> | <p>1 point is earned for the correct answer with justification.</p> |
|---------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|---------------------------------------------------------------------|

- (d) Are there sufficient data obtained in the experiments to determine the value of the equilibrium constant,  $K_p$ , for the decomposition of  $\text{CaCO}_3(s)$  at 1100 K? Justify your answer.

## SCORING GUIDELINES

## Question continued)

|                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                             |                                                                                                            |
|---------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|------------------------------------------------------------------------------------------------------------|
| <p>Yes. For the equilibrium reaction represented by the chemical equation in this problem, at a given temperature the equilibrium pressure of <math>\text{CO}_2</math> determines the equilibrium constant. Since the measured pressure of <math>\text{CO}_2</math> is also the equilibrium pressure of <math>\text{CO}_2</math>, <math>K_p = P_{\text{CO}_2} = 1.04</math>.</p> <p>Note: If the response in part (b) indicates “yes”, that all of the <math>\text{CaCO}_3(s)</math> had decomposed, then the point can be earned by stating that the system did not reach equilibrium in either experiment and hence the value of <math>K_p</math> cannot be calculated from the data.</p> | <p>1 point is earned for correct explanation that is consistent with the student’s answer to part (b).</p> |
|---------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|------------------------------------------------------------------------------------------------------------|

## SCORING GUIDELINES

Question 5  
(4 points)

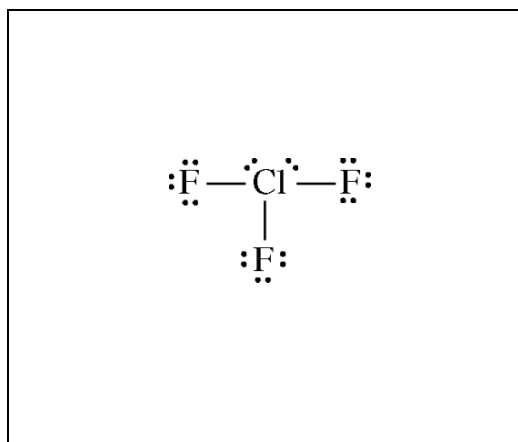
|                     |                 |                 |                 |             |                  |                 |                 |             |
|---------------------|-----------------|-----------------|-----------------|-------------|------------------|-----------------|-----------------|-------------|
| Nonmetal            | C               | N               | O               | Ne          | Si               | P               | S               | Ar          |
| Formula of Compound | CF <sub>4</sub> | NF <sub>3</sub> | OF <sub>2</sub> | No compound | SiF <sub>4</sub> | PF <sub>3</sub> | SF <sub>2</sub> | No compound |

Some binary compounds that form between fluorine and various nonmetals are listed in the table above. A student examines the data in the table and poses the following hypothesis: the number of F atoms that will bond to a nonmetal is always equal to 8 minus the number of valence electrons in the nonmetal atom.

- (a) Based on the student's hypothesis, what should be the formula of the compound that forms between chlorine and fluorine?

|     |                                            |
|-----|--------------------------------------------|
| ClF | 1 point is earned for the correct formula. |
|-----|--------------------------------------------|

- (b) In an attempt to verify the hypothesis, the student researches the fluoride compounds of the other halogens and finds the formula ClF<sub>3</sub>. In the box below, draw a complete Lewis electron-dot diagram for a molecule of ClF<sub>3</sub>.



|                    |                                                                                                                                                                                                                                              |
|--------------------|----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| See diagram above. | 1 point is earned for a central Cl atom surrounded by three bonding pairs with F atoms and two nonbonding (lone) pairs of electrons. F atoms must have three nonbonding pairs each. Electron pairs can be depicted as dots or line segments. |
|--------------------|----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|

## SCORING GUIDELINES

## Question 5 (continued)

- (c) Two possible geometric shapes for the  $\text{ClF}_3$  molecule are trigonal planar and T-shaped. The student does some research and learns that the molecule has a dipole moment. Which of the two shapes is consistent with the fact that the  $\text{ClF}_3$  molecule has a dipole moment? Justify your answer in terms of bond polarity and molecular structure.

|                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                     |                                                                                                       |
|-----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|-------------------------------------------------------------------------------------------------------|
| <p>The molecule is T-shaped</p> <p>because a T-shaped structure is asymmetric with dipoles that do not cancel out, but produce a net dipole (i.e., a polar molecule).</p> <p>OR</p> <p>because, if the molecule had a trigonal planar structure, the molecule would be symmetric with dipoles that cancel out and produce a net dipole of zero (i.e., a nonpolar molecule), which is not consistent with the observation that the <math>\text{ClF}_3</math> molecule does have a dipole moment.</p> | <p>1 point is earned for indicating that the molecule is T-shaped with an acceptable explanation.</p> |
|-----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|-------------------------------------------------------------------------------------------------------|

In an attempt to resolve the existence of the  $\text{ClF}_3$  molecule with the hypothesis stated above, the student researches the compounds that form between halogens and fluorine, and assembles the following list.

| Halogen | Formula(s)                                                  |
|---------|-------------------------------------------------------------|
| F       | $\text{F}_2$                                                |
| Cl      |                                                             |
| Br      | $\text{BrF}$ , $\text{BrF}_3$ , $\text{BrF}_5$              |
| I       | $\text{IF}$ , $\text{IF}_3$ , $\text{IF}_5$ , $\text{IF}_7$ |

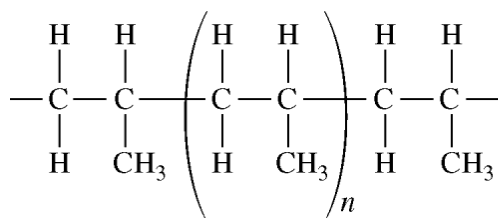
- (d) Based on concepts of atomic structure and periodicity, propose a modification to the student's previous hypothesis to account for the compounds that form between halogens and fluorine.

|                                                                                                                                                                                                                                                                                                                             |                                                                                                                      |
|-----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|----------------------------------------------------------------------------------------------------------------------|
| <p>An acceptable hypothesis (descriptive or formulaic) must include the following ideas:</p> <ol style="list-style-type: none"> <li>1. Atomic Structure: e.g., odd number of F atoms</li> <li>2. Periodicity: e.g., as the atomic number of the central halogen atom increases, the number of F atoms increases.</li> </ol> | <p>1 point is earned for an acceptably modified hypothesis that addresses both atomic structure and periodicity.</p> |
|-----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|----------------------------------------------------------------------------------------------------------------------|

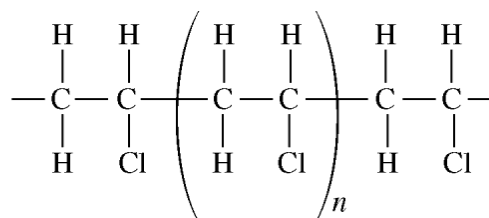
## SCORING GUIDELINES

Question  
(4 points)

A student places a mixture of plastic beads consisting of polypropylene (PP) and polyvinyl chloride (PVC) in a 1.0 L beaker containing distilled water. After stirring the contents of the beaker vigorously, the student observes that the beads of one type of plastic sink to the bottom of the beaker and the beads of the other type of plastic float on the water. The chemical structures of PP and PVC are represented by the diagrams below, which show segments of each polymer.



PP



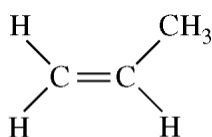
PVC

- (a) Given that the spacing between polymer chains in PP and PVC is similar, the beads that sink are made of which polymer? Explain.

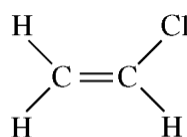
The PVC beads sink. The spacing between chains is similar, but a Cl atom has a greater mass than CH<sub>3</sub>.

1 point is earned for the correct polymer with a correct explanation.

PP is synthesized from propene, C<sub>3</sub>H<sub>6</sub>, and PVC is synthesized from vinyl chloride, C<sub>2</sub>H<sub>3</sub>Cl. The structures of the molecules are shown below.



Propene



Vinyl Chloride (chloroethene)

- (b) The boiling point of liquid propene (226 K) is lower than the boiling point of liquid vinyl chloride (260 K). Account for this difference in terms of the types and strengths of intermolecular forces present in each liquid.

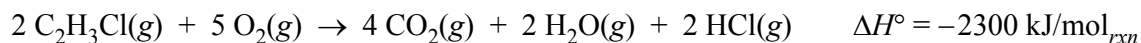
Both substances have dipole-dipole interactions and London dispersion forces (or propene is essentially nonpolar with only LDFs while vinyl chloride has both LDFs and dipole-dipole forces). Propene contains a CH<sub>3</sub> group, but vinyl chloride contains a Cl atom. Vinyl chloride thus has a larger electron cloud, is more polarizable, and has a larger dipole moment. Thus intermolecular attractions are stronger in vinyl chloride, which results in it having the higher boiling point.

1 point is earned for a discussion of intermolecular forces and for a comparison of their relative strengths.

## SCORING GUIDELINES

## Question 6 (continued)

In a separate experiment, the student measures the enthalpies of combustion of propene and vinyl chloride. The student determines that the combustion of 2.00 mol of vinyl chloride releases 2300 kJ of energy, according to the equation below.



- (c) Using the table of standard enthalpies of formation below, determine whether the combustion of 2.00 mol of propene releases more, less, or the same amount of energy that 2.00 mol of vinyl chloride releases. Justify your answer with a calculation. The balanced equation for the combustion of 2.00 mol of propene is  $2 \text{C}_3\text{H}_6(g) + 9 \text{O}_2(g) \rightarrow 6 \text{CO}_2(g) + 6 \text{H}_2\text{O}(g)$ .

| Substance                               | $\text{C}_2\text{H}_3\text{Cl}(g)$ | $\text{C}_3\text{H}_6(g)$ | $\text{CO}_2(g)$ | $\text{H}_2\text{O}(g)$ | $\text{HCl}(g)$ | $\text{O}_2(g)$ |
|-----------------------------------------|------------------------------------|---------------------------|------------------|-------------------------|-----------------|-----------------|
| Standard Enthalpy of Formation (kJ/mol) | 37                                 | 21                        | -394             | -242                    | -92             | 0               |

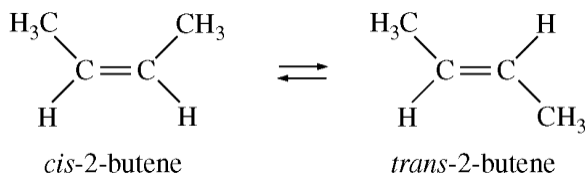
$$\Delta H^\circ = 6(-394) + 6(-242) - 2(21) = -3858 \text{ kJ/mol}_{\text{rxn}}$$

The combustion of 2.00 mol of propene releases more energy.

1 point is earned for the calculation of the enthalpy of combustion of propene.

1 point is earned for the comparison of propene to vinyl chloride that is consistent with the calculated value.

## SCORING GUIDELINES

Question 7  
(4 points)

The half-life ( $t_{1/2}$ ) of the catalyzed isomerization of *cis*-2-butene gas to produce *trans*-2-butene gas, represented above, was measured under various conditions, as shown in the table below.

| Trial Number | Initial $P_{\text{cis-2-butene}}$ (torr) | $V$ (L) | $T$ (K) | $t_{1/2}$ (s) |
|--------------|------------------------------------------|---------|---------|---------------|
| 1            | 300.                                     | 2.00    | 350.    | 100.          |
| 2            | 600.                                     | 2.00    | 350.    | 100.          |
| 3            | 300.                                     | 4.00    | 350.    | 100.          |
| 4            | 300.                                     | 2.00    | 365     | 50.           |

- (a) The reaction is first order. Explain how the data in the table are consistent with a first-order reaction.

|                                                                                                                                                    |                                              |
|----------------------------------------------------------------------------------------------------------------------------------------------------|----------------------------------------------|
| For a first-order reaction, the half-life is independent of reactant concentration (or pressure) at constant $T$ , as shown in trials 1, 2, and 3. | 1 point is earned for a correct explanation. |
|----------------------------------------------------------------------------------------------------------------------------------------------------|----------------------------------------------|

- (b) Calculate the rate constant,  $k$ , for the reaction at 350. K. Include appropriate units with your answer.

|                                                                                     |                                                            |
|-------------------------------------------------------------------------------------|------------------------------------------------------------|
| $k = \frac{0.693}{t_{1/2}} = \frac{0.693}{100. \text{ s}} = 0.00693 \text{ s}^{-1}$ | 1 point is earned for correct numerical answer with units. |
|-------------------------------------------------------------------------------------|------------------------------------------------------------|

- (c) Is the initial rate of the reaction in trial 1 greater than, less than, or equal to the initial rate in trial 2 ? Justify your answer.

|                                                                                                                                                                                                                                                                                                                                                                                 |                                                              |
|---------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|--------------------------------------------------------------|
| <p>The initial rate in trial 1 is less than that in trial 2 because <math>\text{rate} = k[\text{cis-2-butene}]</math> or <math>\text{rate} = kP_{\text{cis-2-butene}}</math> (with reference to values from both trials).</p> <p>OR</p> <p>because the initial concentration of <i>cis</i>-2-butene in trial 1 is less than that in trial 2 and <math>k</math> is constant.</p> | 1 point is earned for the correct answer with justification. |
|---------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|--------------------------------------------------------------|

- (d) The half-life of the reaction in trial 4 is less than the half-life in trial 1. Explain why, in terms of activation energy.

|                                                                                                                                                                                                                                                                |                                                            |
|----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|------------------------------------------------------------|
| The temperature is higher in trial 4, meaning that the $KE_{\text{avg}}$ of the molecules is greater. Consequently, in this trial a greater fraction of collisions have sufficient energy to overcome the activation energy barrier, thus the rate is greater. | 1 point is earned for a correct answer with justification. |
|----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|------------------------------------------------------------|