AP® CHEMISTRY
2012 SCORING GUIDELINES

Question 2
(10 points)

A sample of a pure, gaseous hydrocarbon is introduced into a previously evacuated rigid 1.00 L vessel. The pressure of the gas is 0.200 atm at a temperature of 127°C.

(a) Calculate the number of moles of the hydrocarbon in the vessel.

$n = \frac{PV}{RT} = \frac{(0.200\text{ atm})(1.00\text{ L})}{(0.0821\text{ L atm mol}^{-1}\text{ K}^{-1})(400.\text{ K})}$ $n = 6.09 \times 10^{-3}$ mol	1 point is earned for the setup. 1 point is earned for the numerical answer.

(b) $O_2(g)$ is introduced into the same vessel containing the hydrocarbon. After the addition of the $O_2(g)$, the total pressure of the gas mixture in the vessel is 1.40 atm at 127°C. Calculate the partial pressure of $O_2(g)$ in the vessel.

$P_{O_2} = 1.40\text{ atm} - 0.200\text{ atm} = 1.20\text{ atm}$	1 point is earned for the correct pressure.

The mixture of the hydrocarbon and oxygen is sparked so that a complete combustion reaction occurs, producing $CO_2(g)$ and $H_2O(g)$. The partial pressures of these gases at 127°C are 0.600 atm for $CO_2(g)$ and 0.800 atm for $H_2O(g)$. There is $O_2(g)$ remaining in the container after the reaction is complete.

(c) Use the partial pressures of $CO_2(g)$ and $H_2O(g)$ to calculate the partial pressure of the $O_2(g)$ consumed in the combustion.

$\ldots C_xH_y + \ldots O_2 \rightarrow \ldots CO_2 + \ldots H_2O$ before rxn: 0.200 atm 1.20 atm - - after rxn: 0 atm ? atm 0.600 atm 0.800 atm $0.600\text{ atm } CO_2 \left(\frac{1\text{ atm } O_2}{1\text{ atm } CO_2}\right) = 0.600\text{ atm } O_2$ $0.800\text{ atm } H_2O \left(\frac{1\text{ atm } O_2}{2\text{ atm } H_2O}\right) = 0.400\text{ atm } O_2$ Total O_2 consumed = 1.000 atm **OR**, based on $PV = nRT$ and mole calculations: $n_{H_2O} = \frac{PV}{RT} = \frac{(0.800\text{ atm})(1.00\text{ L})}{(0.0821\text{ L atm mol}^{-1}\text{ K}^{-1})(400.\text{ K})} = 0.0244\text{ mol } H_2O \times \frac{1\text{ mol } O_2}{2\text{ mol } H_2O}$ $= 0.0122\text{ mol } O_2$ $n_{CO_2} = \frac{PV}{RT} = \frac{(0.600\text{ atm})(1.00\text{ L})}{(0.0821\text{ L atm mol}^{-1}\text{ K}^{-1})(400.\text{ K})} = 0.0183\text{ mol } CO_2 \times \frac{1\text{ mol } O_2}{1\text{ mol } CO_2}$ $= 0.0183\text{ mol } O_2$ Total moles $O_2 = 0.0305$; $P = \frac{nRT}{V} = \frac{(0.0305\text{ mol})(0.0821\text{ L atm mol}^{-1}\text{ K}^{-1})(400.\text{ K})}{1.00\text{ L}}$ $P = 1.00\text{ atm } O_2$	1 point is earned for the correct stoichiometry in O_2 consumption. 1 point is earned for the calculated result.

Question 2 (continued)

(d) On the basis of your answers above, write the balanced chemical equation for the combustion reaction and determine the formula of the hydrocarbon.

The partial pressures occur in the same proportions as the number of moles. $P_{\text{hydrocarbon}} : P_{O_2} : P_{CO_2} : P_{H_2O}$ 0.200 atm : 1.00 atm : 0.600 atm : 0.800 atm = 1 : 5 : 3 : 4 $C_3H_8 + 5\,O_2 \rightarrow 3\,CO_2 + 4\,H_2O$ **OR** $n_{H_2O} = \frac{PV}{RT} = \frac{(0.800\text{ atm})(1.00\text{ L})}{(0.0821\text{ L atm mol}^{-1}\text{ K}^{-1})(400.\text{ K})} = 0.0244\text{ mol } H_2O \times \frac{2\text{ mol H}}{1\text{ mol } H_2O}$ $= 0.0487$ mol H $n_{CO_2} = \frac{PV}{RT} = \frac{(0.600\text{ atm})(1.00\text{ L})}{(0.0821\text{ L atm mol}^{-1}\text{ K}^{-1})(400.\text{ K})} = 0.0183\text{ mol } CO_2 \times \frac{1\text{ mol C}}{1\text{ mol } CO_2}$ $= 0.0183$ mol C $\frac{0.0487\text{ mol H}}{0.0183\text{ mol C}} = \left(\frac{2.66\text{ mol H}}{1\text{ mol C}}\right)\left(\frac{3}{3}\right) = \frac{8\text{ mol H}}{3\text{ mol C}} \Rightarrow C_3H_8$ $C_3H_8 + 5\,O_2 \rightarrow 3\,CO_2 + 4\,H_2O$	1 point is earned for the formula of the hydrocarbon. 1 point is earned for a balanced equation with the correct proportions among reactants and products.

(e) Calculate the mass of the hydrocarbon that was combusted.

mass = (number of moles)(molar mass) $= (6.09 \times 10^{-3}\text{ mol})(44.1\text{ g/mol}) = 0.269$ g	1 point is earned for using the number of moles combusted from part (a). 1 point is earned for the calculated mass.

(f) As the vessel cools to room temperature, droplets of liquid water form on the inside walls of the container. Predict whether the pH of the water in the vessel is less than 7, equal to 7, or greater than 7. Explain your prediction.

The pH will be less than 7 because CO_2 is soluble in water, with which it reacts to form H^+ ions.	1 point is earned for the correct choice and explanation.

2A 1

2. A sample of a pure, gaseous hydrocarbon is introduced into a previously evacuated rigid 1.00 L vessel. The pressure of the gas is 0.200 atm at a temperature of 127°C.

(a) Calculate the number of moles of the hydrocarbon in the vessel.

(b) $O_2(g)$ is introduced into the same vessel containing the hydrocarbon. After the addition of the $O_2(g)$, the total pressure of the gas mixture in the vessel is 1.40 atm at 127°C. Calculate the partial pressure of $O_2(g)$ in the vessel.

The mixture of the hydrocarbon and oxygen is sparked so that a complete combustion reaction occurs, producing $CO_2(g)$ and $H_2O(g)$. The partial pressures of these gases at 127°C are 0.600 atm for $CO_2(g)$ and 0.800 atm for $H_2O(g)$. There is $O_2(g)$ remaining in the container after the reaction is complete.

(c) Use the partial pressures of $CO_2(g)$ and $H_2O(g)$ to calculate the partial pressure of the $O_2(g)$ consumed in the combustion.

(d) On the basis of your answers above, write the balanced chemical equation for the combustion reaction and determine the formula of the hydrocarbon.

(e) Calculate the mass of the hydrocarbon that was combusted.

(f) As the vessel cools to room temperature, droplets of liquid water form on the inside walls of the container. Predict whether the pH of the water in the vessel is less than 7, equal to 7, or greater than 7. Explain your prediction.

a) $PV = nRT$

$(0.200\ atm)(1L) = n\ (0.08206\ \frac{L \cdot atm}{mol \cdot K})(400.2°K)$

$n = 0.00609\ mol$

b) $P_{O_2} + P_{Hydrocarbon} = P_{Total}$

$P_{O_2} + 0.200\ atm = 1.40\ atm$

$P_{O_2} = 1.20\ atm$

c) For every mol of CO_2 produced, 1 mol of O_2 is consumed

For every mol of H_2O produced, $\frac{1}{2}$ mol O_2 is consumed

Thus, $P_{O_2\ consumed} = P_{CO_2\ produced} + \frac{1}{2} P_{H_2O\ produced}$ (Since $n \sim P$)

$P_{O_2\ consumed} = 0.6 + \frac{1}{2}(0.8)$

$P_{O_2\ consumed} = 1.00 atm$

GO ON TO THE NEXT PAGE.

ADDITIONAL PAGE FOR ANSWERING QUESTION 2

d) $0.2\ \text{Hydrocarbon} + \text{[illegible]}\ O_2 \rightarrow 0.6\ CO_2 + 0.8\ \text{[illegible]}\ H_2O$

$1\ \text{Hydrocarbon} + 5\ O_2 \rightarrow 3\ CO_2 + 4\ H_2O$

The formula for the hydrocarbon is C_3H_8

The balanced reaction is $C_3H_{8(g)} + 5\,O_{2(g)} \rightarrow 3\,CO_{2(g)} + 4\,H_2O_{(g)}$

e) $0.00609\ \text{mol}\ C_3H_8 \left(\frac{44.11\ g}{1\ \text{mol}\ C_3H_8}\right) = \boxed{0.2686\ g}$

f) The pH will be less than 7, since $CO_{2(g)}$ is present in the chamber. CO_2 reacts with water by the equation

$CO_{2(g)} + H_2O_{(\ell)} \leftrightarrow H_2CO_{3(aq)}$

The H_2CO_3 is acidic, and dissociates to give

$H_2CO_{3(aq)} \leftrightarrow H^+_{(aq)} + HCO_3^-{}_{(aq)}$,

thus making the water acidic.

GO ON TO THE NEXT PAGE.

2B

2. A sample of a pure, gaseous hydrocarbon is introduced into a previously evacuated rigid 1.00 L vessel. The pressure of the gas is 0.200 atm at a temperature of 127°C.

(a) Calculate the number of moles of the hydrocarbon in the vessel.

(b) $O_2(g)$ is introduced into the same vessel containing the hydrocarbon. After the addition of the $O_2(g)$, the total pressure of the gas mixture in the vessel is 1.40 atm at 127°C. Calculate the partial pressure of $O_2(g)$ in the vessel.

The mixture of the hydrocarbon and oxygen is sparked so that a complete combustion reaction occurs, producing $CO_2(g)$ and $H_2O(g)$. The partial pressures of these gases at 127°C are 0.600 atm for $CO_2(g)$ and 0.800 atm for $H_2O(g)$. There is $O_2(g)$ remaining in the container after the reaction is complete.

(c) Use the partial pressures of $CO_2(g)$ and $H_2O(g)$ to calculate the partial pressure of the $O_2(g)$ consumed in the combustion.

(d) On the basis of your answers above, write the balanced chemical equation for the combustion reaction and determine the formula of the hydrocarbon.

(e) Calculate the mass of the hydrocarbon that was combusted.

(f) As the vessel cools to room temperature, droplets of liquid water form on the inside walls of the container. Predict whether the pH of the water in the vessel is less than 7, equal to 7, or greater than 7. Explain your prediction.

a) $PV = nRT$

$(0.200\,atm)(1.00\,L) = n(0.0821\,L\,atm\,mol^{-1}\,K^{-1})(400\,K)$

$n = .00609$ moles

b) ~~P_{tot}~~ $P_{tot} = P_{O_2} + P_{Hydrocarbon}$

$1.40\,atm = P_{O_2} + .200\,atm$ $\quad P_{O_2} = 1.20\,atm$

c) $PV = nRT$

$(0.800)(1.00\,L) = n(0.0821)(400)$

$n = .0244\,mol\,H_2O \times \frac{1\,mol\,O}{1\,mol} = .0244\,mol\,O$

$(0.600)(1.00\,L) = n(0.0821)(400)$

$n = .0183\,mol\,CO_2 \times \frac{2\,mol\,O}{1\,mol} = .0365\,mol\,O$

$+$

$.0609\,mol\,O$

$.0609\,mol\,O \times \frac{1\,mol\,O_2}{2\,mol\,O} = .0305\,mol\,O_2$

2B2

$P(1.00L) = (.0305 mol)(0.0821)(400)$

$P = 1.00$ atm consumed O_2

d) $.0305 mol\ O_2 / .0183 mol\ CO_2 = 1\frac{2}{3} \times 3 = 5$

$.0244 mol\ H_2O / .0183 mol\ CO_2 = 1\frac{1}{3} \times 3 = 4$

$.0183 mol\ CO_2 / .0183 mol\ CO_2 = 1 \times 3 = 3$

$C_xH_y + 5O_2 \rightarrow 4H_2O + 3CO_2$

3 carbon ~~8H~~

$C_3H_8 + 5O_2 \rightarrow 4H_2O + 3CO_2$

e) from Part (a) $.00609 mol \times \frac{44g\ C_3H_8}{1 mol\ C_3H_8} = 2.68g\ C_3H_8$

f) The pH of the vessel is equal to 7 because water is forming and water has a pH of 7

2C,

2. A sample of a pure, gaseous hydrocarbon is introduced into a previously evacuated rigid 1.00 L vessel. The pressure of the gas is 0.200 atm at a temperature of 127°C.

(a) Calculate the number of moles of the hydrocarbon in the vessel.

(b) $O_2(g)$ is introduced into the same vessel containing the hydrocarbon. After the addition of the $O_2(g)$, the total pressure of the gas mixture in the vessel is 1.40 atm at 127°C. Calculate the partial pressure of $O_2(g)$ in the vessel.

The mixture of the hydrocarbon and oxygen is sparked so that a complete combustion reaction occurs, producing $CO_2(g)$ and $H_2O(g)$. The partial pressures of these gases at 127°C are 0.600 atm for $CO_2(g)$ and 0.800 atm for $H_2O(g)$. There is $O_2(g)$ remaining in the container after the reaction is complete.

(c) Use the partial pressures of $CO_2(g)$ and $H_2O(g)$ to calculate the partial pressure of the $O_2(g)$ consumed in the combustion.

(d) On the basis of your answers above, write the balanced chemical equation for the combustion reaction and determine the formula of the hydrocarbon.

(e) Calculate the mass of the hydrocarbon that was combusted.

(f) As the vessel cools to room temperature, droplets of liquid water form on the inside walls of the container. Predict whether the pH of the water in the vessel is less than 7, equal to 7, or greater than 7. Explain your prediction.

a) $(.2)(1) = n(.0821)(400)$

$n = .00609$ moles

b) $1.4 = .2 + P_{O_2}$

$P_{O_2} = 1.2$ atm

c) $2.8 = .2 + .6 + .8 + P_{O_2}$

$P_{O_2} = 1.2$ atm

2C2

d) $4HC + 5O_2 \rightarrow 4CO_2 + 2H_2O$

e) $.00609 \text{ moles } HC \left| \frac{13 \text{ g}}{1 \text{ mol}} \right. = .0792 \text{ g } HC$

f) It will be greater than 7 because combustions are basic reactions.

AP® CHEMISTRY
2012 SCORING COMMENTARY

Question 2

Overview

This question assessed students' understanding of and ability to solve problems and explain concepts that pertain to the reaction of gaseous reactants and products. Parts of the question required calculation. Students were presented with a known pressure of an unknown gaseous hydrocarbon in a rigid vessel at a constant temperature. Part (a) required the students to calculate the number of moles of the unknown gaseous hydrocarbon. Part (b) required students to determine the partial pressure of oxygen gas given the total pressure after the addition of some oxygen gas to the vessel. Part (c) required students to calculate the partial pressure of the oxygen gas that reacted in the hydrocarbon combustion reaction given the partial pressures of the CO_2 gas and H_2O gas that formed. Part (d) required the students to write the balanced equation based on the partial pressures both given and calculated and determine the formula of the hydrocarbon. Part (e) required the students to calculate the mass of the hydrocarbon that reacted and part (f) required the students to predict the pH in the reaction vessel after it had cooled and drops of liquid water formed on the inside of the container.

Sample: 2A
Score: 10

The response earned 2 points in part (a) for the calculated number of moles of the hydrocarbon (1 point for the setup, and 1 point for the correct calculated value). In part (b) the response earned 1 point for the correct calculated partial pressure of oxygen gas in the reaction vessel. In part (c) the response earned 2 points for the partial pressure of the reacted oxygen gas. The first of the 2 points was earned for recognizing that one can use the stoichiometric ratio of moles of oxygen gas to moles of H_2O or moles of oxygen gas to moles of CO_2 to determine the corresponding partial pressure of the oxygen gas reacted. The second point was earned for the correct final answer. In part (d) the response earned 1 point for the correct balanced chemical equation from ratios of partial pressures and 1 point for the correct formula of the hydrocarbon. In part (e) 1 point was earned for using the number of moles of the hydrocarbon from part (a) and 1 point was earned for correctly calculating the number of grams of hydrocarbon that reacted using the correct molar mass of the hydrocarbon. In part (f) the response earned 1 point for correctly predicting that the pH is less than 7 with an acceptable argument.

Sample: 2B
Score: 8

The response earned 1 point in part (e) for using the number of moles of the hydrocarbon from part (a), but a calculation error resulted in the second point not being earned. Part (f) did not earn the point because the student incorrectly predicts that the pH is equal to 7 in the vessel after cooling. The response earned all other available points.

Sample: 2C
Score: 6

The response did not earn points in part (c). In part (d) 1 point was earned for correctly balancing a combustion reaction with an incorrect hydrocarbon formula. Part (e) earned 2 points: 1 point for using the number of moles of hydrocarbon reacted from part (a), and another point for using the molar mass of the species given in the answer to part (d) and getting a consistent answer. The response in part (f) did not earn the point because of an incorrect prediction of the pH of the reaction vessel after cooling. The response earned all other available points.