AP® CHEMISTRY
2009 SCORING GUIDELINES

Question 2 (10 points)

A student was assigned the task of determining the molar mass of an unknown gas. The student measured the mass of a sealed 843 mL rigid flask that contained dry air. The student then flushed the flask with the unknown gas, resealed it, and measured the mass again. Both the air and the unknown gas were at 23.0°C and 750. torr. The data for the experiment are shown in the table below.

Volume of sealed flask	843 mL
Mass of sealed flask and dry air	157.70 g
Mass of sealed flask and unknown gas	158.08 g

(a) Calculate the mass, in grams, of the dry air that was in the sealed flask. (The density of dry air is 1.18 g L^{-1} at 23.0°C and 750. torr.)

$m = D \times V = (1.18 \text{ g L}^{-1})(0.843 \text{ L}) =$ **0.995 g**	One point is earned for the correct setup and calculation of mass.

(b) Calculate the mass, in grams, of the sealed flask itself (i.e., if it had no air in it).

157.70 g – 0.995 g = **156.71 g**	One point is earned for subtracting the answer in part (a) from 157.70 g.

(c) Calculate the mass, in grams, of the unknown gas that was added to the sealed flask.

158.08 g – 156.71 g = **1.37 g**	One point is earned for subtracting the answer in part (b) from 158.08 g.

(d) Using the information above, calculate the value of the molar mass of the unknown gas.

$n = \frac{PV}{RT} = \frac{\left(\frac{750.}{760}\text{atm}\right)(0.843 \text{ L})}{(0.0821 \text{ L atm mol}^{-1} \text{ K}^{-1})(296 \text{ K})} = 0.0342 \text{ mol}$ molar mass $= \frac{1.37 \text{ g}}{0.0342 \text{ mol}} =$ **40.1 g mol^{-1}** **OR** molar mass $= \frac{DRT}{P}$ $= \frac{\left(\frac{1.37 \text{ g}}{0.843 \text{ L}}\right)(0.0821 \text{ L atm mol}^{-1} \text{ K}^{-1})(296 \text{ K})}{\left(\frac{750.}{760}\text{atm}\right)}$ = **40.0 g mol^{-1}**	One point is earned for the conversion of pressure (if necessary) and temperature and the use of the appropriate R. One point is earned for the correct setup and calculation of moles of gas. One point is earned for the correct setup and calculation of molar mass. **OR** If calculation is done in a single step, 1 point is earned for the correct P and T, 1 point is earned for the correct density, and 1 point is earned for the correct answer.

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Question 2 (continued)

After the experiment was completed, the instructor informed the student that the unknown gas was carbon dioxide ($44.0\ g\ mol^{-1}$).

(e) Calculate the percent error in the value of the molar mass calculated in part (d).

$\text{percent error} = \dfrac{\left\lvert 44.0\ g\,mol^{-1} - 40.1\ g\,mol^{-1} \right\rvert}{44.0\ g\,mol^{-1}} \times 100 = 8.9\%$	One point is earned for the correct setup and answer.

(f) For each of the following two possible occurrences, indicate whether it by itself could have been responsible for the error in the student's experimental result. You need not include any calculations with your answer. For each of the possible occurrences, justify your answer.

Occurrence 1: The flask was incompletely flushed with $CO_2(g)$, resulting in some dry air remaining in the flask.

This occurrence could have been responsible. The dry air left in the flask is less dense (or has a lower molar mass) than CO_2 gas at the given T and P. This would result in a lower mass of gas in the flask and a lower result for the molar mass of the unknown gas.	One point is earned for the correct reasoning and conclusion.

Occurrence 2: The temperature of the air was 23.0°C, but the temperature of the $CO_2(g)$ was lower than the reported 23.0°C.

This occurrence could not have been responsible. The density of CO_2 is greater at the lower temperature. A larger mass of CO_2 would be in the flask than if the CO_2 had been at 23.0°C, resulting in a higher calculated molar mass for the unknown gas.	One point is earned for the correct reasoning and conclusion.

(g) Describe the steps of a laboratory method that the student could use to verify that the volume of the rigid flask is 843 mL at 23.0°C. You need not include any calculations with your answer.

Valid methods include the following: 1. Find the mass of the empty flask. Fill the flask with a liquid of known density (e.g., water at 23°C), and measure the mass of the liquid-filled flask. Subtract to find the mass of the liquid. Using the known density and mass, calculate the volume. 2. Measure 843 mL of a liquid (e.g., water) in a 1,000 mL graduated cylinder and transfer the liquid quantitatively into the flask to see if the water fills the flask completely.	One point is earned for a valid method.

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Question 2 (continued)

Note: Significant figures were checked in this problem: parts (a) and (d) were scored with ±1 significant figure needed, and parts (b) and (c) were scored with the correct number of significant figures needed for the subtraction.

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2. A student was assigned the task of determining the molar mass of an unknown gas. The student measured the mass of a sealed 843 mL rigid flask that contained dry air. The student then flushed the flask with the unknown gas, resealed it, and measured the mass again. Both the air and the unknown gas were at 23.0°C and 750. torr. The data for the experiment are shown in the table below.

Volume of sealed flask	843 mL
Mass of sealed flask and dry air	157.70 g
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(a) Calculate the mass, in grams, of the dry air that was in the sealed flask. (The density of dry air is 1.18 g L^{-1} at 23.0°C and 750. torr.)

(b) Calculate the mass, in grams, of the sealed flask itself (i.e., if it had no air in it).

(c) Calculate the mass, in grams, of the unknown gas that was added to the sealed flask.

(d) Using the information above, calculate the value of the molar mass of the unknown gas.

After the experiment was completed, the instructor informed the student that the unknown gas was carbon dioxide (44.0 g mol^{-1}).

(e) Calculate the percent error in the value of the molar mass calculated in part (d).

(f) For each of the following two possible occurrences, indicate whether it by itself could have been responsible for the error in the student's experimental result. You need not include any calculations with your answer. For each of the possible occurrences, justify your answer.

Occurrence 1: The flask was incompletely flushed with $CO_2(g)$, resulting in some dry air remaining in the flask.

Occurrence 2: The temperature of the air was 23.0°C, but the temperature of the $CO_2(g)$ was lower than the reported 23.0°C.

(g) Describe the steps of a laboratory method that the student could use to verify that the volume of the rigid flask is 843 mL at 23.0°C. You need not include any calculations with your answer.

(A) $843\,mL \times \frac{1\,L}{1000\,mL} = 0.843\,L \times \frac{1.18\,g}{L} = 0.995\,g$ dry air

(B) $157.70\,g_{\text{Flask + air}} - 0.995\,g_{\text{air}} = 156.71\,g = $ Mass of flask

(C) $158.08\,g_{\text{Flask + gas}} - 156.71\,g_{\text{Flask}} = 1.37\,g = $ Mass of unknown gas

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ADDITIONAL PAGE FOR ANSWERING QUESTION 2

(D) $PV=nRT$ $\quad P = 750\,\text{torr} \times \frac{1\,\text{atm}}{760\,\text{torr}} = 0.987\,\text{atm}$

$V = 0.843\,L \quad T = 23.0^\circ + 273 = 296\,K$

$n = \frac{PV}{RT}$

$n = \frac{(0.987\,\text{atm})(0.843\,L)}{(0.0821\,L\text{-atm/mol-K})(296\,K)} = 0.0342\,\text{mol unknown gas}$

$\frac{1.37\,g\ \text{unknown gas}}{0.0342\,\text{mol unknown gas}} = \boxed{40.1\,g\,mol^{-1}}$

(E) $\%\,\text{error} = \frac{|\text{acc} - \text{expl}|}{\text{acc}} \times 100$

$\%\,\text{error} = \frac{|44.0 - 40.1|}{44.0} \times 100 = \boxed{8.9\%\ \text{error}}$

(F) • Occurence 1 could have been responsible for the error since dry air is lighter than CO_2 the mass of unknown gas would be lower than it should be resulting in a lower molar mass.

• Occurence 2 could not have been responsible for the error because at lower temps gas is more dense making more grams of gas in the flask which would make our molar mass higher than it should be, which it's not.

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ADDITIONAL PAGE FOR ANSWERING QUESTION 2

(G) The student could fill the flask with water and measure its volume in a graduated cylinder.

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Volume of sealed flask	843 mL
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(b) Calculate the mass, in grams, of the sealed flask itself (i.e., if it had no air in it).

(c) Calculate the mass, in grams, of the unknown gas that was added to the sealed flask.

(d) Using the information above, calculate the value of the molar mass of the unknown gas.

After the experiment was completed, the instructor informed the student that the unknown gas was carbon dioxide (44.0 g mol^{-1}).

(e) Calculate the percent error in the value of the molar mass calculated in part (d).

(f) For each of the following two possible occurrences, indicate whether it by itself could have been responsible for the error in the student's experimental result. You need not include any calculations with your answer. For each of the possible occurrences, justify your answer.

Occurrence 1: The flask was incompletely flushed with $CO_2(g)$, resulting in some dry air remaining in the flask.

Occurrence 2: The temperature of the air was 23.0°C, but the temperature of the $CO_2(g)$ was lower than the reported 23.0°C.

(g) Describe the steps of a laboratory method that the student could use to verify that the volume of the rigid flask is 843 mL at 23.0°C. You need not include any calculations with your answer.

a) $843\ mL \times \frac{1\ L}{1000\ mL} = .843\ L$

$\Rightarrow d = 1.18\ g/L$

$\Rightarrow (.843\ L)(1.18\ g/L)$

$\Rightarrow$ **mass of dry air = .995 g**

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ADDITIONAL PAGE FOR ANSWERING QUESTION 2

b) Total mass (flask and air) = 157.70 g

⇒ mass of flask = 157.70 g − .995 g

⇒ **mass of flask = 156.71 g**

c) Mass of flask and gas = 158.08 g

⇒ mass of unknown gas = 158.08 g − 156.71 g

⇒ **mass of unknown gas = 1.37 g**

d) $PV = nRT$

$P = 750.\text{ torr}$ $\quad R = 62.4 \frac{\text{torr} \cdot \text{L}}{\text{K} \cdot \text{mol}}$

$V = 843\text{ mL} = .843\text{ L}$ $\quad T = 23.0^\circ\text{C} = 296\text{ K}$

$\Rightarrow (750\text{ torr})(.843\text{ L}) = n\left(62.4 \frac{\text{torr} \cdot \text{L}}{\text{K} \cdot \text{mol}}\right)(296\text{ K})$

$\Rightarrow n = .0342\text{ mol unknown gas}$

$\text{Molar mass} = \frac{g}{n} = \frac{1.37\text{ g}}{.0342\text{ mol}}$

⇒ **MM unknown gas = 40.0 g/mol**

e) $\text{Percent Error} = \frac{|O - E|}{E} \times 100$

$\Rightarrow \%\text{ Error} = \frac{44 - 40}{44} \times 100$

⇒ **% Error = 9.09 %**

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ADDITIONAL PAGE FOR ANSWERING QUESTION 2

f) Occurrence 1 could not have been responsible for the error because then the calculated mass would have been greater than was actually present, increasing the molar mass, but the actual molar mass was larger than the experimentally-determined value, so that could not have been the reason

Occurrence 2 could have been responsible because this decreases the overall temperature, which in turn increases the number moles of gas present, decreasing the molar mass and the molar mass was lower than the actual value.

g) The student could fill the flask completely with water and then pour the water into 100-mL graduated cylinders until the total volume was determined.

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(b) Calculate the mass, in grams, of the sealed flask itself (i.e., if it had no air in it).

(c) Calculate the mass, in grams, of the unknown gas that was added to the sealed flask.

(d) Using the information above, calculate the value of the molar mass of the unknown gas.

After the experiment was completed, the instructor informed the student that the unknown gas was carbon dioxide (44.0 g mol^{-1}).

(e) Calculate the percent error in the value of the molar mass calculated in part (d).

(f) For each of the following two possible occurrences, indicate whether it by itself could have been responsibl for the error in the student's experimental result. You need not include any calculations with your answer. For each of the possible occurrences, justify your answer.

Occurrence 1: The flask was incompletely flushed with $CO_2(g)$, resulting in some dry air remaining in the flask.

Occurrence 2: The temperature of the air was 23.0°C, but the temperature of the $CO_2(g)$ was lower than the reported 23.0°C.

(g) Describe the steps of a laboratory method that the student could use to verify that the volume of the rigid flask is 843 mL at 23.0°C. You need not include any calculations with your answer.

(a) $\frac{1.18\text{ g}}{1\text{ L}} \times \frac{843\text{ mL}}{1} \times \frac{1\text{ L}}{10^3\text{ mL}} = 0.995\text{ g of dry air.}$

(b) $157.70\text{ g} - 0.995\text{ g} = 156.71\text{ g} \Rightarrow$ flasked.

(c) $158.08\text{ g} - 156.71\text{ g} = 1.37\text{ g}$ of unknown gas

(d) $\frac{1.37\text{ g}}{1} \times \frac{1}{0.843\text{ L}} \times \frac{22.4\text{ L}}{1\text{ mol}} = 36.5\text{ g/mol}$

(e) $\frac{|44.0 - 36.5|}{44.0} \times 100\% = 17\%$

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ADDITIONAL PAGE FOR ANSWERING QUESTION 2

(f) Occurrence 1: Yes.
If there was remaining dry air in the flask, the measured / calculated mass of the unknown gas would be higher than it actually is.
Occurrence 2: No.
Temperature would not affect mass or moles of the unknown gas.

(g) 1. Fill the flask with water and seal it.
2. Pour all the water out and measure the volume of it.
3. Record the volume of the flask in mL.

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2009 SCORING COMMENTARY

Question 2

Overview

This question assessed students' knowledge and skills related to determining the molar mass of an unknown gas, which is one of the laboratory experiments recommended in the *AP Chemistry Course Description.* In parts (a) through (c) students were asked to analyze data by calculating the mass of the dry air in the flask at the beginning of the experiment, the mass of the flask itself, and the mass of the unknown gas. In part (d) they were expected to recognize that the conditions of the experiment were not standard and therefore a conversion of temperature to Kelvin and possibly pressure to match the *R* was required. Students had to substitute values into an appropriate equation to solve for moles and then calculate molar mass by dividing grams of unknown gas by the calculated number of moles. In part (e) students were asked to calculate the percent error for the experiment based on the molar mass calculated in part (d) and the given molar mass of CO_2. Part (f) involved error analysis: students were given two different errors and asked to decide if either error could have led to the answer reported in part (d) and to justify their answers. In part (g) students were asked to describe an appropriate laboratory method to verify the volume of the sealed flask used in the experiment.

Sample: 2A
Score: 10

This response earned all 10 points: 1 for part (a), 1 for part (b), 1 for part (c), 3 for part (d), 1 for part (e), 2 for part (f), and 1 for part (g).

Sample: 2B
Score: 8

In part (f) neither of the possible 2 points was earned because for each occurrence, the response gives an incorrect conclusion and explanation.

Sample: 2C
Score: 5

In part (d) although 1 point was earned for calculating a molar mass by dividing the answer in part (c) by moles, the other 2 points were not earned because the response ignores the fact that the conditions are nonstandard. In part (f) neither of the possible 2 points was earned because the response for occurrence 1 gives a correct conclusion but an incorrect explanation that contradicts the conclusion and the response for occurrence 2 does not recognize that temperature would make a difference. In part (g) the point was not earned because no measuring instrument is identified.

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