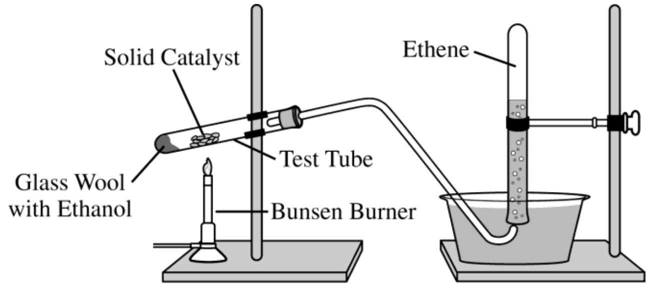
Question 2



Ethene, $C_2H_4(g)$ (molar mass 28.1 g/mol), may be prepared by the dehydration of ethanol, $C_2H_5OH(g)$ (molar mass 46.1 g/mol), using a solid catalyst. A setup for the lab synthesis is shown in the diagram above. The equation for the dehydration reaction is given below.

$$\underset{\text{ethanol}}{C_2H_5OH(g)} \xrightarrow{\text{catalyst}} \underset{\text{ethene}}{C_2H_4(g)} + \underset{\text{water}}{H_2O(g)} \quad \Delta H^\circ_{298} = 45.5 \text{ kJ/mol}_{rxn}; \; \Delta S^\circ_{298} = 126 \text{ J/(K}\cdot\text{mol}_{rxn})$$

A student added a 0.200 g sample of $C_2H_5OH(l)$ to a test tube using the setup shown above. The student heated the test tube gently with a Bunsen burner until all of the $C_2H_5OH(l)$ evaporated and gas generation stopped. When the reaction stopped, the volume of collected gas was 0.0854 L at 0.822 atm and 305 K. (The vapor pressure of water at 305 K is 35.7 torr.)

(a) Calculate the number of moles of $C_2H_4(g)$

(i) that are actually produced in the experiment and measured in the gas collection tube and

$35.7 \text{ torr} \times \dfrac{1 \text{ atm}}{760 \text{ torr}} = 0.0470 \text{ atm}$ $P_{\text{ethene}} = P_{\text{total}} - P_{\text{water}} = 0.822 \text{ atm} - 0.0470 \text{ atm} = 0.775 \text{ atm}$	1 point is earned for the calculation of the pressure of the dry ethene.
$n = \dfrac{PV}{RT} = \dfrac{(0.775 \text{ atm})(0.0854 \text{ L})}{(0.08206 \text{ L atm mol}^{-1} \text{ K}^{-1})(305 \text{ K})} = 0.00264 \text{ mol}$	1 point is earned for the correct number of moles of ethene gas.

(ii) that would be produced if the dehydration reaction went to completion.

$0.200 \text{ g } C_2H_5OH \times \dfrac{1 \text{ mol } C_2H_5OH}{46.1 \text{ g } C_2H_5OH} \times \dfrac{1 \text{ mol } C_2H_4}{1 \text{ mol } C_2H_5OH}$ $= 0.00434 \text{ mol } C_2H_4$ produced	1 point is earned for the correct number of moles of ethene produced.

(b) Calculate the percent yield of $C_2H_4(g)$ in the experiment.

$\% \text{ yield} = \dfrac{\text{actual yield}}{\text{maximum possible yield}} \times 100 = \dfrac{0.00264 \text{ mol}}{0.00434 \text{ mol}} \times 100 = 60.8\%$	1 point is earned for the correct percent yield.

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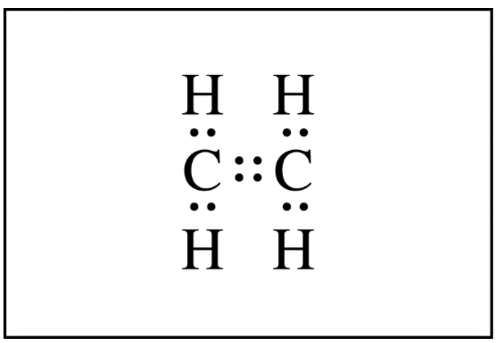
Question 2 (continued)

Because the dehydration reaction is not observed to occur at 298 K, the student claims that the reaction has an equilibrium constant less than 1.00 at 298 K.

(c) Do the thermodynamic data for the reaction support the student's claim? Justify your answer, including a calculation of ΔG°_{298} for the reaction.

Yes, the data support the student's claim. $\Delta G^\circ = \Delta H^\circ - T\Delta S^\circ$ $= 45.5 \text{ kJ/mol}_{rxn} - (298 \text{ K})(0.126 \text{ kJ/(K·mol}_{rxn})) = 8.0 \text{ kJ/mol}_{rxn}$ Because $\Delta G^\circ > 0$, the value of $K_p = e^{(\frac{-\Delta G^\circ}{RT})} < 1.00$.	1 point is earned for the correct calculation of ΔG°. 1 point is earned for a valid justification.

(d) The Lewis electron-dot diagram for C_2H_4 is shown below in the box on the left. In the box on the right, complete the Lewis electron-dot diagram for C_2H_5OH by drawing in all of the electron pairs.



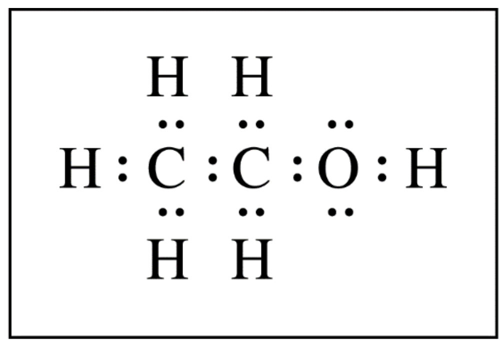


Diagram should include all bonding pairs plus two nonbonding pairs on the O atom. (A line may be used to represent an electron pair.)	1 point is earned for a correct diagram.

(e) What is the approximate value of the C–O–H bond angle in the ethanol molecule?

The bond angle is approximately 109°.	1 point is earned for an angle from 100° to 115°.

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Question 2 (continued)

(f) During the dehydration experiment, $C_2H_4(g)$ and unreacted $C_2H_5OH(g)$ passed through the tube into the water. The C_2H_4 was quantitatively collected as a gas, but the unreacted C_2H_5OH was not. Explain this observation in terms of the intermolecular forces between water and each of the two gases.

Ethene is only slightly soluble in water because the weak dipole/induced dipole intermolecular attractions between nonpolar ethene molecules and polar water molecules are weaker than the hydrogen bonds between water molecules. Ethanol molecules are soluble in water because they are polar and form hydrogen bonds with water molecules as they dissolve.	1 point is earned for comparing the solubility of ethene in water with the solubility of ethanol in water in terms of differences in polarity. 1 point is earned for describing the intermolecular forces between ethene and water as weak dipole/induced dipole forces and attributing the solubility of ethanol in water to the hydrogen bonds formed between ethanol molecules and water molecules.

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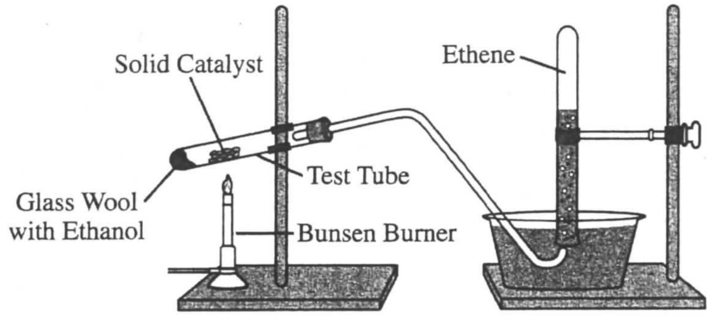


2. Ethene, $C_2H_4(g)$ (molar mass 28.1 g/mol), may be prepared by the dehydration of ethanol, $C_2H_5OH(g)$ (molar mass 46.1 g/mol), using a solid catalyst. A setup for the lab synthesis is shown in the diagram above. The equation for the dehydration reaction is given below.

$$\underset{\text{ethanol}}{C_2H_5OH(g)} \xrightarrow{\text{catalyst}} \underset{\text{ethene}}{C_2H_4(g)} + \underset{\text{water}}{H_2O(g)} \quad \Delta H^\circ_{298} = 45.5\ \text{kJ/mol}_{rxn};\ \Delta S^\circ_{298} = 126\ \text{J/(K}\cdot\text{mol}_{rxn})$$

A student added a 0.200 g sample of $C_2H_5OH(l)$ to a test tube using the setup shown above. The student heated the test tube gently with a Bunsen burner until all of the $C_2H_5OH(l)$ evaporated and gas generation stopped. When the reaction stopped, the volume of collected gas was 0.0854 L at 0.822 atm and 305 K. (The vapor pressure of water at 305 K is 35.7 torr.)

(a) Calculate the number of moles of $C_2H_4(g)$

(i) that are actually produced in the experiment and measured in the gas collection tube and

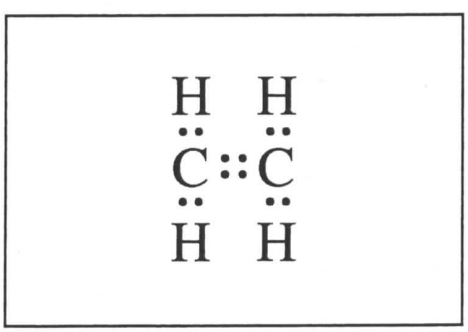
(ii) that would be produced if the dehydration reaction went to completion.

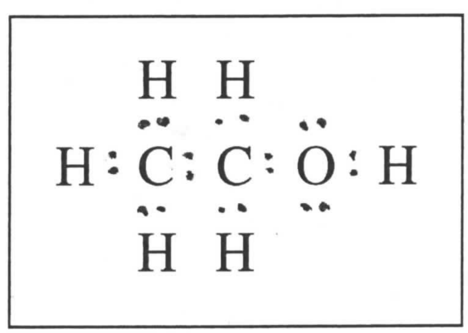
(b) Calculate the percent yield of $C_2H_4(g)$ in the experiment.

Because the dehydration reaction is not observed to occur at 298 K, the student claims that the reaction has an equilibrium constant less than 1.00 at 298 K.

(c) Do the thermodynamic data for the reaction support the student's claim? Justify your answer, including a calculation of ΔG°_{298} for the reaction.

(d) The Lewis electron-dot diagram for C_2H_4 is shown below in the box on the left. In the box on the right, complete the Lewis electron-dot diagram for C_2H_5OH by drawing in all of the electron pairs.





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(e) What is the approximate value of the C–O–H bond angle in the ethanol molecule?

(f) During the dehydration experiment, $C_2H_4(g)$ and unreacted $C_2H_5OH(g)$ passed through the tube into the water. The C_2H_4 was quantitatively collected as a gas, but the unreacted C_2H_5OH was not. Explain this observation in terms of the intermolecular forces between water and each of the two gases.

a) (i) $P_{gas} = P_{atmosphere} - P_{vapor}$

$P_{gas} = 0.822 \text{ atm} - 35.7 \text{ torr} \times \frac{1 \text{ atm}}{760 \text{ torr}}$

$P_{gas} = 0.775 \text{ atm}$

$PV = nRT$

$(0.775 \text{ atm})(0.0854 \text{ L}) = n\left(0.0821 \frac{\text{atm}\cdot\text{L}}{\text{K}\cdot\text{mol}}\right)(305 \text{ K})$

$n = 0.00264 \text{ mol}$

0.00264 mol were actually produced

(ii) $0.200 \text{g } C_2H_5OH \times \frac{\text{mol } C_2H_5OH}{46.1 \text{g}} \times \frac{1 \text{ mol } C_2H_4}{1 \text{ mol } C_2H_5OH} = 0.00434$

0.00434 mol would actually be produced if the reaction went to completion.

b) C_2H_4 Percent yield $= \frac{\text{Actual yield}}{\text{Theoretical yield}} \times 100\%$

$= \frac{0.00264 \text{ mol}}{0.00434 \text{ mol}} \times 100\%$

$= 60.8\%$

c) Yes, the data supports the student's claim.

$\Delta G^\circ_{298} = \Delta H^\circ_{298} - T\Delta S^\circ_{298}$

$\Delta G^\circ_{298} = 45.5 \text{ kJ/mol} - (298 \text{ K})(126 \text{ J/K}\cdot\text{mol})$

$\Delta G^\circ_{298} = 7.95 \text{ kJ/mol}$

Since ΔG°_{298} is positive, the reaction is non spontaneous

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at this temperature, and therefore the concentration of the reactants will be higher than that of the products, resulting in an equilibrium constant less than 1.00

e) Since there are 4 electron domains around the O molecule, and 2 have electron pairs, the bond angle will be less than that of a tetrahedral molecule, but close to its 109.5°.

f) Since the C_2H_5OH is polar, it was dissolved in the polar solvent - water. The hydrogen bonding between C_2H_5OH and water overcame the energy required to break the hydrogen bonds between water molecules while the weaker London-Dispersion forces formed between C_2H_4 and water could not.

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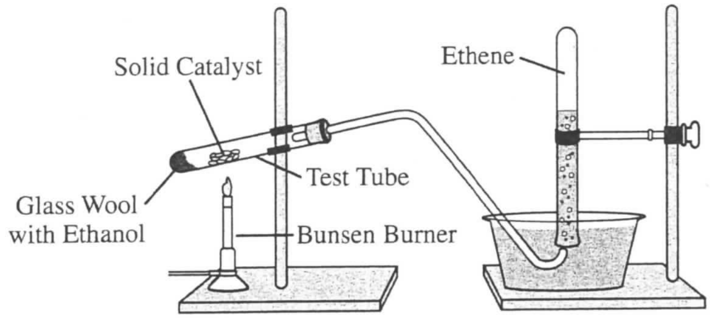


2. Ethene, $C_2H_4(g)$ (molar mass 28.1 g/mol), may be prepared by the dehydration of ethanol, $C_2H_5OH(g)$ (molar mass 46.1 g/mol), using a solid catalyst. A setup for the lab synthesis is shown in the diagram above. The equation for the dehydration reaction is given below.

$$\underset{\text{ethanol}}{C_2H_5OH(g)} \xrightarrow{\text{catalyst}} \underset{\text{ethene}}{C_2H_4(g)} + \underset{\text{water}}{H_2O(g)} \quad \Delta H^\circ_{298} = 45.5\ \text{kJ/mol}_{rxn};\ \Delta S^\circ_{298} = 126\ \text{J/(K}\cdot\text{mol}_{rxn})$$

A student added a 0.200 g sample of $C_2H_5OH(l)$ to a test tube using the setup shown above. The student heated the test tube gently with a Bunsen burner until all of the $C_2H_5OH(l)$ evaporated and gas generation stopped. When the reaction stopped, the volume of collected gas was 0.0854 L at 0.822 atm and 305 K. (The vapor pressure of water at 305 K is 35.7 torr.)

(a) Calculate the number of moles of $C_2H_4(g)$

(i) that are actually produced in the experiment and measured in the gas collection tube and

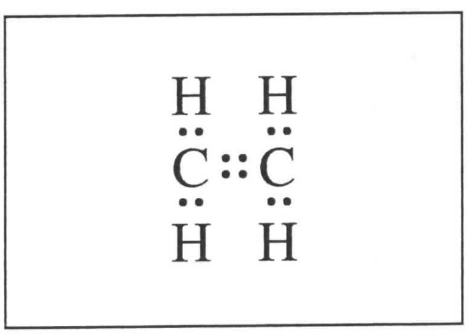
(ii) that would be produced if the dehydration reaction went to completion.

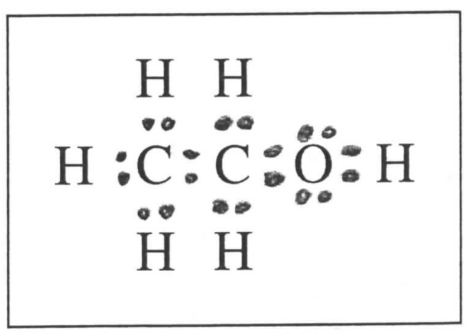
(b) Calculate the percent yield of $C_2H_4(g)$ in the experiment.

Because the dehydration reaction is not observed to occur at 298 K, the student claims that the reaction has an equilibrium constant less than 1.00 at 298 K.

(c) Do the thermodynamic data for the reaction support the student's claim? Justify your answer, including a calculation of ΔG°_{298} for the reaction.

(d) The Lewis electron-dot diagram for C_2H_4 is shown below in the box on the left. In the box on the right, complete the Lewis electron-dot diagram for C_2H_5OH by drawing in all of the electron pairs.





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(e) What is the approximate value of the C−O−H bond angle in the ethanol molecule?

(f) During the dehydration experiment, $C_2H_4(g)$ and unreacted $C_2H_5OH(g)$ passed through the tube into the water. The C_2H_4 was quantitatively collected as a gas, but the unreacted C_2H_5OH was not. Explain this observation in terms of the intermolecular forces between water and each of the two gases.

A) I) $PV=nRT$

$(0.822\text{ atm})(0.0854\text{ L}) = n(0.0821 \frac{\text{L}\cdot\text{atm}}{\text{mol K}})(305\text{ K})$

$\frac{(0.822)(0.0854)}{(0.0821)(305)}\text{ mol} = n$

$.00280\text{ mol } C_2H_4 = n$

II) $0.200\text{ g}\left(\frac{1\text{ mol}}{46.1\text{ g}}\right) = .00434\text{ mol } C_2H_5OH = .00434\text{ mol } C_2H_5OH$

B) $\frac{.00280\text{ mol}}{.00434\text{ mol}} \times 100 = 64.5\%$ yield

C) $\Delta G^\circ_{298} = \Delta H^\circ_{298} - T\Delta S^\circ_{298}$

$\Delta G^\circ_{298} = 45.5\text{ kJ/mol} - (298\text{K})(.126\text{ kJ/K mol})$

$\Delta G^\circ_{298} = 7.95\text{ kJ/mol}$

Yes, the thermodynamic data supports this claim. Since ΔG°_{298} is positive, lnK must be negative. This can only occur if K (the equilibrium constant) is less than 1.00

D) (see diagram)

E) The approximate value of the C-O-H bond angle is 120°.

F) This observation occurs because $C_2H_5OH_{(g)}$ is polar while $C_2H_{4(g)}$ is not. The C_2H_5OH will exhibit strong

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dipole-dipole attraction to the water, even hydrogen bonding, while the C_2H_4 will exhibit only London dispersion forces. This will cause the C_2H_4 to pass through the water, while the C_2H_5OH will not.

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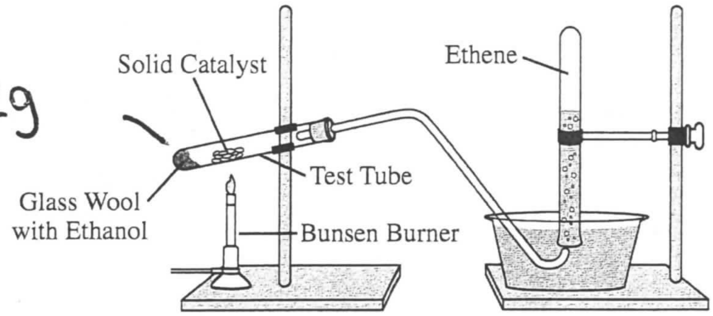

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A student added a 0.200 g sample of $C_2H_5OH(l)$ to a test tube using the setup shown above. The student heated the test tube gently with a Bunsen burner until all of the $C_2H_5OH(l)$ evaporated and gas generation stopped. When the reaction stopped, the volume of collected gas was 0.0854 L at 0.822 atm and 305 K. (The vapor pressure of water at 305 K is 35.7 torr.)

$q = mc\Delta T$

$PV = nRT$

(a) Calculate the number of moles of $C_2H_4(g)$

(i) that are actually produced in the experiment and measured in the gas collection tube and

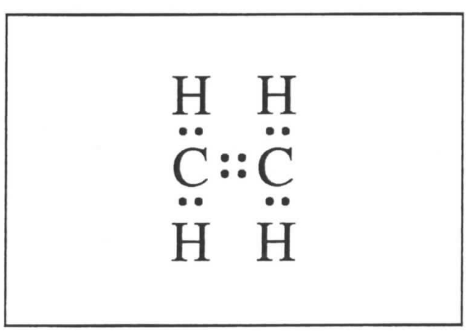
(ii) that would be produced if the dehydration reaction went to completion.

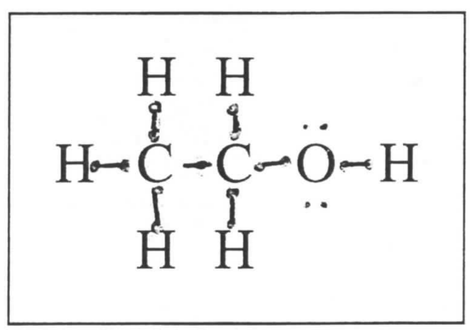
(b) Calculate the percent yield of $C_2H_4(g)$ in the experiment.

Because the dehydration reaction is not observed to occur at 298 K, the student claims that the reaction has an equilibrium constant less than 1.00 at 298 K.

(c) Do the thermodynamic data for the reaction support the student's claim? Justify your answer, including a calculation of ΔG°_{298} for the reaction.

(d) The Lewis electron-dot diagram for C_2H_4 is shown below in the box on the left. In the box on the right, complete the Lewis electron-dot diagram for C_2H_5OH by drawing in all of the electron pairs.





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(e) What is the approximate value of the C–O–H bond angle in the ethanol molecule?

(f) During the dehydration experiment, $C_2H_4(g)$ and unreacted $C_2H_5OH(g)$ passed through the tube into the water. The C_2H_4 was quantitatively collected as a gas, but the unreacted C_2H_5OH was not. Explain this observation in terms of the intermolecular forces between water and each of the two gases.

a. (i) $PV = nRT$

$(.822 \text{ atm})(.0854 L) = n(.08206 \text{ L·atm/mol·K})(305 K)$

$n = \boxed{0.00280 \text{ moles}}$

(ii) $\frac{0.200 \text{ g } C_2H_5OH}{} \left| \frac{1 \text{ mol ethanol}}{46.1 \text{ g}} \right| \frac{1 \text{ mol ethene}}{1 \text{ mol ethanol}} = \boxed{0.00434 \text{ moles}}$

b. $\frac{0.00280}{0.00434} \cdot 100 = \boxed{64.5\% \text{ percent yield}}$

c. $\Delta G = \Delta H - \Delta S T$

$\Delta G_{298} = 45.5 - .126 \cdot 298$

$\Delta G_{298} = \boxed{7.95 \text{ kJ/mol}}$

$\Delta G = -RT \ln K$

$7952 \text{ J} = -8.314 \cdot 298 \ln K$

$\boxed{K = 0.0404}$

The students claim is supported with the data. Using the calculated ΔG the constant was found to be less than 1.00 at 298 K, the K value was found to be 0.0404.

e. 180°

f. The $H_2O(g)$ cools and condenses back to a liquid during the experiment. The $C_2H_4(g)$ stays in the gas phase and rises in the experiment to the top of the collecting test tube. The unreacted C_2H_5OH will remain in the original test tube because its molar mass holds it down.

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Question 2

Overview

Question 2 was designed to evaluate student understanding and ability to analyze data generated empirically during common laboratory procedures. Students were presented with a picture of laboratory equipment arranged for the collection of gas over water in a dehydration experiment.

The students were given the chemical equation for the reaction that occurs in the experiment. They were given data, and they were asked in part (a) to calculate the experimental yield in moles at a certain time in the experiment. Then they were asked to calculate the theoretical yield in moles if the reaction proceeded to completion. In part (b) students were asked to use their calculations to determine the percent yield. In part (c) students used given thermodynamic data to verify a student's claim about the K_p of the reaction. In part (d) students were instructed to complete a Lewis electron-dot diagram for a molecule. In part (e) students were asked to give the value of the bond angle in a certain part of the molecule based on their Lewis diagram from part (d). Finally in part (f) students applied their conceptual understanding of intermolecular forces to explain experimental observations of the difference in the water solubilities of two gases.

Sample: 2A
Score: 10

One point was earned in part (a)(i) for the correct calculation of the pressure of the dry gas. The second point was earned for the correct calculation of the number of moles of ethene gas. The vapor pressure of water is given in torr and the pressure of the gaseous mixture in atmospheres. To earn this point, a conversion to the same units is required before subtracting the $P_{H_2O(g)}$ from P_{total}. The ideal gas law and an R value consistent with the units used for pressure are used to calculate the number of moles of ethene produced in the experiment (actual yield). The R value must be consistent with the units for pressure. One point was earned in part (a)(ii) for correctly calculating the number of moles of ethene that could have been produced from a given number of grams of ethanol if the reaction had gone to completion (theoretical yield). The equation for the chemical reaction shows a one-to-one ratio of ethanol to ethene. One point was earned in part (b) for correctly calculating the percent yield using the number of moles of ethene produced in the experiment (actual yield) and calculated in part (a)(i), and the theoretical yield calculated in part (a)(ii). One point was earned in part (c) for using the given information to correctly calculate $\Delta G°$. The second point was earned for supporting the student's claim by stating that since $\Delta G°$ is positive, and the reaction is nonspontaneous, the reactants are favored, and K_p is less than 1.00. One point was earned in part (d) for correctly completing the Lewis electron-dot diagram given in the box. One point was earned in part (e) for stating that the C−O−H bond angle in ethanol is 109.5°. One point was earned in part (f) for comparing the solubility of ethene in water with the solubility of ethanol in water in terms of the differences in their polarity. The nonpolar nature of ethene is implied in the last sentence. The second point was earned for attributing the solubility of ethanol in water to ethanol's ability to break the hydrogen bonds between the water molecules, and the insolubility of ethene in water to the weaker London dispersion forces between ethene and water.

Sample: 2B
Score: 8

The first point was not earned in part (a)(i) because the response neglects to calculate the pressure of the water vapor, which is needed to determine the pressure of the dry gas. One point was earned for using the ideal gas law gas law and an R value consistent with the units for pressure to calculate the number of moles of ethene produced in the experiment (actual yield). One point was earned in part (a)(ii) for correctly calculating the number of moles of ethene that could be produced (theoretical yield). One point was earned in part (b) for calculating the percent yield using the number of moles of ethene produced in the experiment

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Question 2 (continued)

(actual yield) calculated in part (a)(i), and the theoretical yield calculated in part (a)(ii). One point was earned in part (c) for the correct calculation of $\Delta G°$. A second point was earned for justifying that the student's claim was valid by stating that since $\Delta G°$ is positive, K_p must be less than 1.00. One point was earned in part (d) for correctly completing the Lewis electron-dot diagram. No point was earned in part (e) because the value given for the C−O−H bond angle in ethanol is incorrect. One point was earned in part (f) for using differences in polarity to compare the water solubilities of ethene and ethanol. The second point was earned in part (f) for correctly relating solubility to the intermolecular forces of hydrogen bonding and London dispersion forces.

Sample: 2C
Score: 6

The first point was not earned in part (a)(i) because the response neglects to calculate the pressure of the water vapor, which is needed to determine the pressure of the dry gas. One point was earned for using the ideal gas law and an R value consistent with the units for pressure to calculate the number of moles of ethene produced in the experiment (actual yield). One point was earned in part (a)(ii) for correctly calculating the number of moles of ethene that could be produced (theoretical yield). One point was earned in part (b) for calculating the percent yield using the number of moles of ethene produced in the experiment (actual yield) calculated in part (a)(i), and the theoretical yield calculated in part (a)(ii). One point was earned in part (c) for the correct calculation of $\Delta G°$. A second point was earned for indicating that the student's claim is valid by using $\Delta G°$ to correctly calculate K_p, which is less than 1.00. One point was earned in part (d) for correctly completing the Lewis electron-dot diagram. The point was not earned in part (e) because the value given for the C−O−H bond angle in ethanol is incorrect. No points were earned in part (f) for an answer based on molar mass and phase changes that neglects to discuss water solubility based on the intermolecular forces between water and each of the two gases.

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