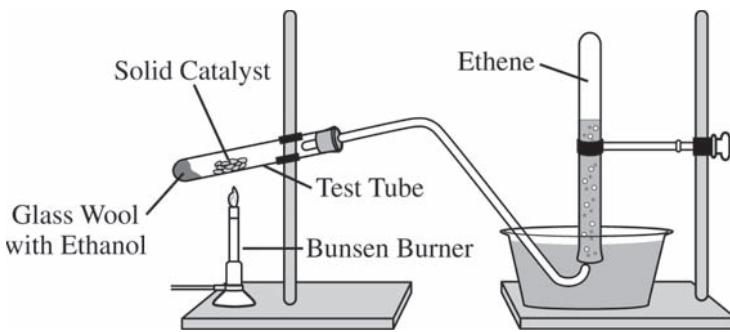
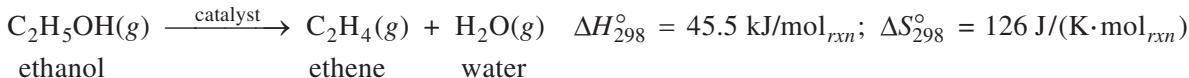


**2015 AP® CHEMISTRY FREE-RESPONSE QUESTIONS**



2. Ethene,  $\text{C}_2\text{H}_4(g)$  (molar mass 28.1 g/mol), may be prepared by the dehydration of ethanol,  $\text{C}_2\text{H}_5\text{OH}(g)$  (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.



A student added a 0.200 g sample of  $\text{C}_2\text{H}_5\text{OH}(l)$  to a test tube using the setup shown above. The student heated the test tube gently with a Bunsen burner until all of the  $\text{C}_2\text{H}_5\text{OH}(l)$  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  $\text{C}_2\text{H}_4(g)$

  - (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.

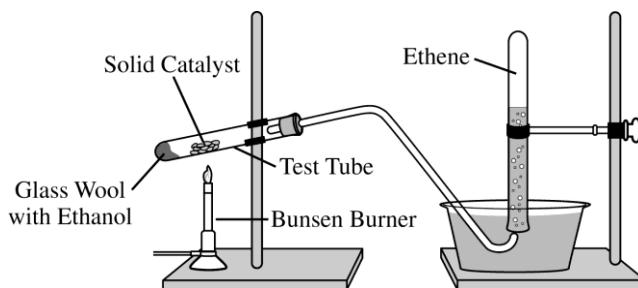
(b) Calculate the percent yield of  $\text{C}_2\text{H}_4(g)$  in the experiment.

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.

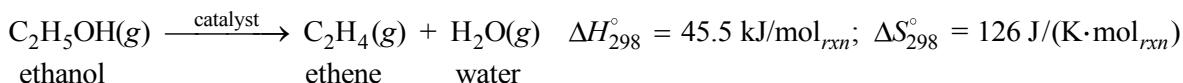
- (c) Do the thermodynamic data for the reaction support the student's claim? Justify your answer, including a calculation of  $\Delta G_{298}^\circ$  for the reaction.

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## Question 2



Ethene,  $\text{C}_2\text{H}_4(g)$  (molar mass 28.1 g/mol), may be prepared by the dehydration of ethanol,  $\text{C}_2\text{H}_5\text{OH}(g)$  (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.



A student added a 0.200 g sample of  $\text{C}_2\text{H}_5\text{OH}(l)$  to a test tube using the setup shown above. The student heated the test tube gently with a Bunsen burner until all of the  $\text{C}_2\text{H}_5\text{OH}(l)$  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  $\text{C}_2\text{H}_4(g)$

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

$$35.7 \text{ torr} \times \frac{1 \text{ atm}}{760 \text{ torr}} = 0.0470 \text{ atm}$$

$$P_{\text{ethene}} = P_{\text{total}} - P_{\text{water}} = 0.822 \text{ atm} - 0.0470 \text{ atm} = 0.775 \text{ atm}$$

$$n = \frac{PV}{RT} = \frac{(0.775 \text{ atm})(0.0854 \text{ L})}{(0.08206 \text{ L atm mol}^{-1} \text{ K}^{-1})(305 \text{ K})} = 0.00264 \text{ mol}$$

1 point is earned for the calculation of the pressure of the dry ethene.

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.

$$0.200 \text{ g C}_2\text{H}_5\text{OH} \times \frac{1 \text{ mol C}_2\text{H}_5\text{OH}}{46.1 \text{ g C}_2\text{H}_5\text{OH}} \times \frac{1 \text{ mol C}_2\text{H}_4}{1 \text{ mol C}_2\text{H}_5\text{OH}}$$

= 0.00434 mol C<sub>2</sub>H<sub>4</sub> produced

1 point is earned for the correct number of moles of ethene produced.

- (b) Calculate the percent yield of  $\text{C}_2\text{H}_4(g)$  in the experiment.

$$\% \text{ yield} = \frac{\text{actual yield}}{\text{maximum possible yield}} \times 100 = \frac{0.00264 \text{ mol}}{0.00434 \text{ mol}} \times 100 = 60.8\%$$

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  $\Delta G_{298}^\circ$  for the reaction.

Yes, the data support the student's claim.

$$\Delta G^\circ = \Delta H^\circ - T\Delta S^\circ$$

$$= 45.5 \text{ kJ/mol}_{rxn} - (298 \text{ K})(0.126 \text{ kJ/(K}\cdot\text{mol}_{rxn})) = 8.0 \text{ kJ/mol}_{rxn}$$

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  $\Delta G^\circ$ .

1 point is earned for a valid justification.

- (d) The Lewis electron-dot diagram for  $\text{C}_2\text{H}_4$  is shown below in the box on the left. In the box on the right, complete the Lewis electron-dot diagram for  $\text{C}_2\text{H}_5\text{OH}$  by drawing in all of the electron pairs.

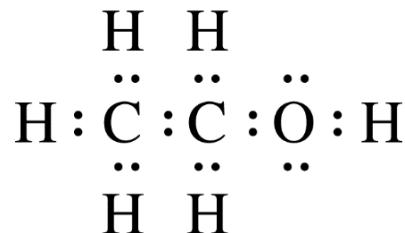
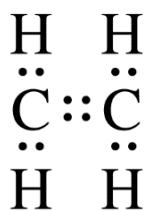


Diagram should include all bonding pairs plus two nonbonding pairs on the O atom. (A line may be used to represent an electron pair.)

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  $109^\circ$ .

1 point is earned for an angle from  $100^\circ$  to  $115^\circ$ .

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**Question 2 (continued)**

- (f) During the dehydration experiment,  $\text{C}_2\text{H}_4(g)$  and unreacted  $\text{C}_2\text{H}_5\text{OH}(g)$  passed through the tube into the water. The  $\text{C}_2\text{H}_4$  was quantitatively collected as a gas, but the unreacted  $\text{C}_2\text{H}_5\text{OH}$  was not. Explain this observation in terms of the intermolecular forces between water and each of the two gases.

<p>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.</p>	<p>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.</p>
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