2019

AP® CollegeBoard

AP® Chemistry

Sample Student Responses and Scoring Commentary

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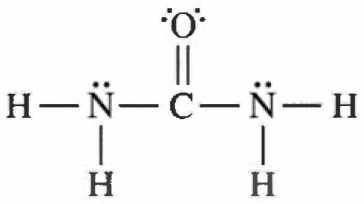
AP® CHEMISTRY
2019 SCORING GUIDELINES

Question 1

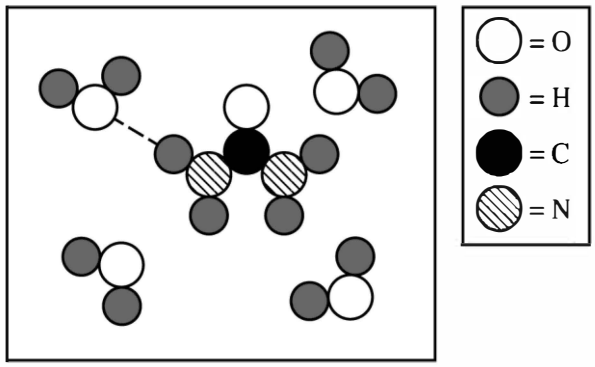


The compound urea, H_2NCONH_2, is widely used in chemical fertilizers. The complete Lewis electron-dot diagram for the urea molecule is shown above.

(a) Identify the hybridization of the valence orbitals of the carbon atom in the urea molecule.

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

(b) Urea has a high solubility in water, due in part to its ability to form hydrogen bonds. A urea molecule and four water molecules are represented in the box below. Draw ONE dashed line (----) to indicate a possible location of a hydrogen bond between a water molecule and the urea molecule.



A dashed line should connect a hydrogen atom in water to a nitrogen or oxygen atom in urea or an oxygen atom in water to a hydrogen atom in urea. One possible correct response is shown above.	1 point is earned for a correct answer.

$$H_2NCONH_2(s) \rightleftarrows H_2NCONH_2(aq)$$

The dissolution of urea is represented by the equation above. A student determines that 5.39 grams of H_2NCONH_2 (molar mass 60.06 g/mol) can dissolve in water to make 5.00 mL of a saturated solution at 20.°C.

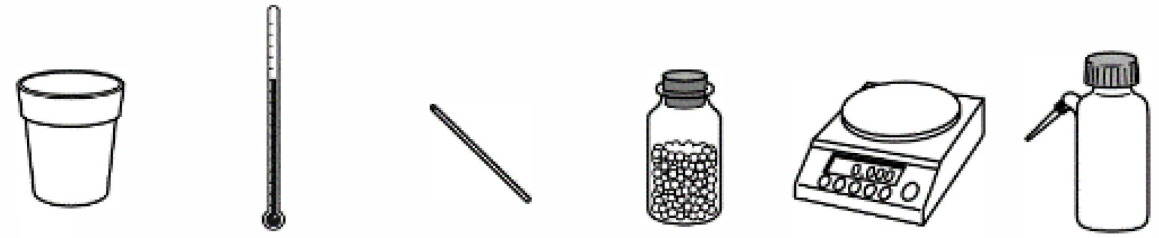
Question 1 (continued)

(c) Calculate the concentration of urea, in mol/L, in the saturated solution at 20.°C.

$5.39 \text{ g } H_2NCONH_2 \times \frac{1 \text{ mol}}{60.06 \text{ g}} = 0.0897 \text{ mol}$ $\frac{0.0897 \text{ mol}}{0.00500 \text{ L}} = 17.9 \ M$	1 point is earned for the correct number of moles of urea (may be implicit). 1 point is earned for the correct molarity.

(d) The student also determines that the concentration of urea in a saturated solution at 25°C is 19.8 M. Based on this information, is the dissolution of urea endothermic or exothermic? Justify your answer in terms of Le Chatelier's principle.

The increased solubility at the higher temperature implies that the dissolution of urea is endothermic. If a saturated solution of urea is heated, then the equilibrium system is stressed. The stress is counteracted by the endothermic dissolution of more urea.	1 point is earned for the correct answer with an appropriate justification.



(e) The equipment shown above is provided so that the student can determine the value of the molar heat of solution for urea. Knowing that the specific heat of the solution is 4.18 J/(g·°C), list the specific measurements that are required to be made during the experiment.

mass of urea, mass of water, initial temperature of water, final temperature of solution	1 point is earned for the masses. 1 point is earned for the temperatures.

Question 1 (continued)

	$S°$ (J/(mol·K))
$H_2NCONH_2(s)$	104.6
$H_2NCONH_2(aq)$	?

(f) The entropy change for the dissolution of urea, ΔS°_{soln}, is 70.1 J/(mol·K) at 25°C. Using the information in the table above, calculate the absolute molar entropy, $S°$, of aqueous urea.

$\Delta S^\circ_{soln} = S^\circ(H_2NCONH_2(aq)) - S^\circ(H_2NCONH_2(s))$ $70.1 \text{ J/(mol·K)} = S^\circ(H_2NCONH_2(aq)) - 104.6 \text{ J/(mol·K)}$ $S^\circ(H_2NCONH_2(aq)) = 174.7 \text{ J/(mol·K)}$	1 point is earned for the correct answer.

(g) Using particle-level reasoning, explain why ΔS°_{soln} is positive for the dissolution of urea in water.

Urea molecules in solution have a greater number of possible arrangements than in solid urea. This increased number of arrangements corresponds to a positive ΔS°_{soln}.	1 point is earned for a correct explanation.

(h) The student claims that $\Delta S°$ for the process contributes to the thermodynamic favorability of the dissolution of urea at 25°C. Use the thermodynamic information above to support the student's claim.

Thermodynamic favorability for a process at standard conditions is determined by the sign of $\Delta G°$, with $\Delta G° = \Delta H° - T\Delta S°$. Since $\Delta S°$ is positive, the $T\Delta S°$ term makes the value of $\Delta G°$ smaller and thus makes the dissolution more thermodynamically favorable.	1 point is earned for the correct answer.

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CHEMISTRY

Section II

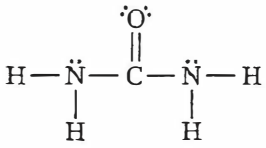
Time—1 hour and 45 minutes

7 Questions

YOU MAY USE YOUR CALCULATOR FOR THIS SECTION.

Directions: Questions 1–3 are long free-response questions that require about 23 minutes each to answer and are worth 10 points each. Questions 4–7 are short free-response questions that require about 9 minutes each to answer and are worth 4 points each.

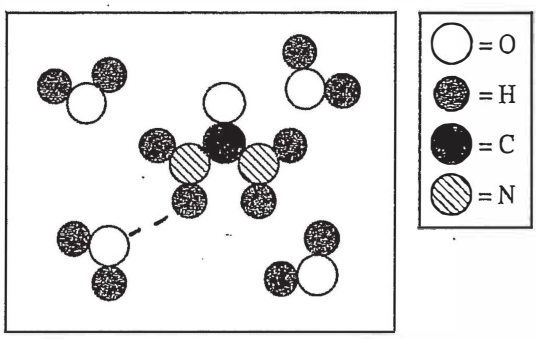
Write your response in the space provided following each question. Examples and equations may be included in your responses where appropriate. For calculations, clearly show the method used and the steps involved in arriving at your answers. You must show your work to receive credit for your answer. Pay attention to significant figures.



1. The compound urea, H_2NCONH_2, is widely used in chemical fertilizers. The complete Lewis electron-dot diagram for the urea molecule is shown above.

   (a) Identify the hybridization of the valence orbitals of the carbon atom in the urea molecule.

   (b) Urea has a high solubility in water, due in part to its ability to form hydrogen bonds. A urea molecule and four water molecules are represented in the box below. Draw ONE dashed line (----) to indicate a possible location of a hydrogen bond between a water molecule and the urea molecule.



$$H_2NCONH_2(s) \rightleftarrows H_2NCONH_2(aq)$$

The dissolution of urea is represented by the equation above. A student determines that 5.39 grams of H_2NCONH_2 (molar mass 60.06 g/mol) can dissolve in water to make 5.00 mL of a saturated solution at 20.°C.

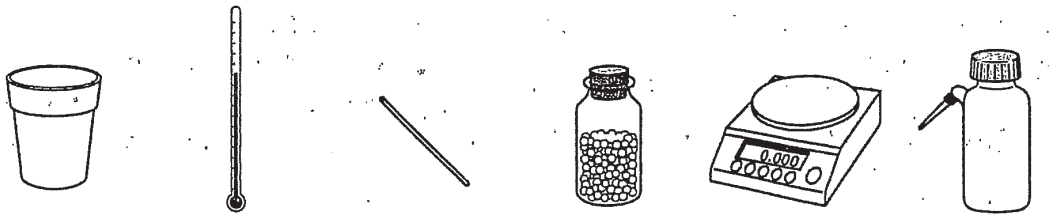
   (c) Calculate the concentration of urea, in mol/L, in the saturated solution at 20.°C.

GO ON TO THE NEXT PAGE.

1A 2 of 4 Molarity increases = more dissolves

(d) The student also determines that the concentration of urea in a saturated solution at 25°C is 19.8 *M*. Based on this information, is the dissolution of urea endothermic or exothermic? Justify your answer in terms of Le Chatelier's principle.

Temp ↑ means endothermic



Polystyrene Cup | Thermometer | Stirring Rod | Bottle of Urea | Balance | Distilled Water

(e) The equipment shown above is provided so that the student can determine the value of the molar heat of solution for urea. Knowing that the specific heat of the solution is 4.18 J/(g·°C), list the specific measurements that are required to be made during the experiment.

	$S°$ (J/(mol·K))
$H_2NCONH_2(s)$	104.6
$H_2NCONH_2(aq)$	?

(f) The entropy change for the dissolution of urea, $\Delta S°_{soln}$, is 70.1 J/(mol·K) at 25°C. Using the information in the table above, calculate the absolute molar entropy, $S°$, of aqueous urea.

(g) Using particle-level reasoning, explain why $\Delta S°_{soln}$ is positive for the dissolution of urea in water.

(h) The student claims that $\Delta S°$ for the process contributes to the thermodynamic favorability of the dissolution of urea at 25°C. Use the thermodynamic information above to support the student's claim.

a) sp^2

b) See diagram

c) $\frac{5.39\text{ g}}{60.06\text{ g/mol}} = .089744\text{ moles}$ $\quad \frac{.089744\text{ moles}}{.005\text{ L}} = 17.95\text{ M}$

d) The dissolution of urea is endothermic. Le Chatelier's principle states that a reaction will move in a direction that will minimize the shift caused by a change. In this case, as the temperature increases, the reaction will shift to the products only if heat is a reactant, indicating that the reaction is endothermic ($+\Delta H$, energy is placed on the reactant side)

e) See next page

ADDITIONAL PAGE FOR ANSWERING QUESTION 1

e)

i. Mass of urea used

ii. Mass of water used (also volume of water)

iii. Initial temperature of water (before adding urea) largest difference

iiii. Final temperature of water (lowest temperature observed in this case)

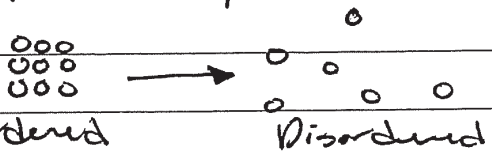
v. Mass of polystyrene cup

f) $\Delta S = 70.1 (J/mol \cdot K)$

$Urea_{(s)}$ $S^\circ = 104.6 (J/mol \cdot K)$

$104.6 + 70.1 = 174.7 (J/mol \cdot K)$ S° $Urea_{(aq)}$

g) $\Delta S^\circ_{solution}$ is positive for this reaction because the dissolution of a solid takes a state that is highly ordered to a state that is disordered. Since the disorder (entropy) increases, the ΔS° is positive



There are more positional probabilities for a liquid than a solid, which also contributes to an increase in entropy.

h) $\Delta G = \Delta H - T\Delta S$

since ΔH is positive (as the reaction is endothermic), ΔS needs to be a large positive number in order to produce a $-\Delta G$ (which relates to a spontaneous [thermodynamically favored] reaction])

GO ON TO THE NEXT PAGE.

ADDITIONAL PAGE FOR ANSWERING QUESTION 1

If ΔS was negative, then it would not relate to a spontaneous reaction as ΔG would be positive.

Note: This is assuming a constant temperature and pressure (298 K and 1 atm)

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CHEMISTRY

Section II

Time—1 hour and 45 minutes

7 Questions

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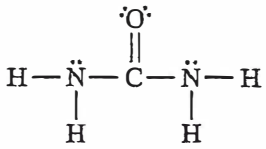
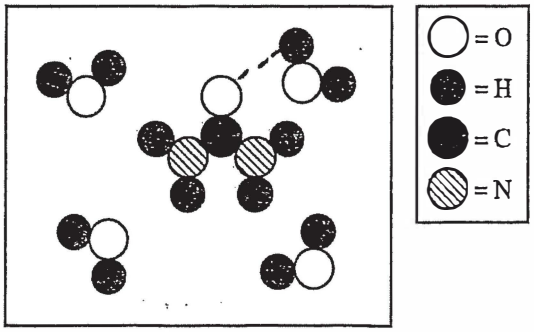


1. The compound urea, H_2NCONH_2, is widely used in chemical fertilizers. The complete Lewis electron-dot diagram for the urea molecule is shown above.

   (a) Identify the hybridization of the valence orbitals of the carbon atom in the urea molecule.

   (b) Urea has a high solubility in water, due in part to its ability to form hydrogen bonds. A urea molecule and four water molecules are represented in the box below. Draw ONE dashed line (----) to indicate a possible location of a hydrogen bond between a water molecule and the urea molecule.



$$H_2NCONH_2(s) \rightleftarrows H_2NCONH_2(aq)$$

The dissolution of urea is represented by the equation above. A student determines that 5.39 grams of H_2NCONH_2 (molar mass 60.06 g/mol) can dissolve in water to make 5.00 mL of a saturated solution at 20.°C.

   (c) Calculate the concentration of urea, in mol/L, in the saturated solution at 20.°C.

(d) The student also determines that the concentration of urea in a saturated solution at 25°C is 19.8 *M*. Based on this information, is the dissolution of urea endothermic or exothermic? Justify your answer in terms of Le Chatelier's principle.

Polystyrene Cup | Thermometer | Stirring Rod | Bottle of Urea | Balance | Distilled Water

(e) The equipment shown above is provided so that the student can determine the value of the molar heat of solution for urea. Knowing that the specific heat of the solution is 4.18 J/(g·°C), list the specific measurements that are required to be made during the experiment.

	$S°$ (J/(mol·K))
$H_2NCONH_2(s)$	104.6
$H_2NCONH_2(aq)$	?

(f) The entropy change for the dissolution of urea, $\Delta S°_{soln}$, is 70.1 J/(mol·K) at 25°C. Using the information in the table above, calculate the absolute molar entropy, $S°$, of aqueous urea.

(g) Using particle-level reasoning, explain why $\Delta S°_{soln}$ is positive for the dissolution of urea in water.

(h) The student claims that $\Delta S°$ for the process contributes to the thermodynamic favorability of the dissolution of urea at 25°C. Use the thermodynamic information above to support the student's claim.

a) sp^2

b) on diagram

c) $5.39\ g\ of\ urea \times \frac{1\ mol\ urea}{66.06\ g\ urea} = 0.082\ mol\ urea$

$M = \frac{0.082\ mol\ urea}{0.005\ L} = 16.4\ mol/L$

GO ON TO THE NEXT PAGE.

D) $H_2NCONH_2(s) \rightleftarrows H_2NCONH_2(aq)$

Since the concentration of urea increased as temperature increased the dissolution of H_2NCONH_2 is endothermic. According to Le Chatelier's principle if the system is disrupt then a shift will be required to get back to equilibrium. In order to increase the concentration of urea heat would have to be a reactant, so the system shifts right.

e) Measure the mass of the solid urea. Record the temperature of the water and solution.

f) $\Delta S^\circ_{soln} = \Delta S^\circ_{products} - \Delta S^\circ_{reactants}$

$70.1\ J/(mol \cdot K) = \Delta S^\circ_{products} - 104.6\ J/(mol \cdot K)$

$\Delta S^\circ_{products} = 174.7\ J/(mol \cdot K) = S^\circ$ of urea (aq)

g) The ΔS°_{soln} is positive because a solid is turning into a liquid so there is more chaos and disorder between the particles.

h) The positive ΔS° is thermodynamically favorable at 25°C because $\Delta G = \Delta H - T\Delta S$, so in order for the dissolution to be favorable $\Delta G < 0$. Since the dissolution

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ADDITIONAL PAGE FOR ANSWERING QUESTION 1

is positive and ΔS° is positive then at higher temperatures the dissolution will be favorable.

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CHEMISTRY

Section II

Time—1 hour and 45 minutes

7 Questions

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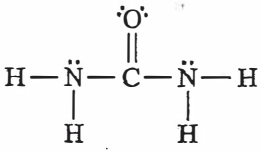
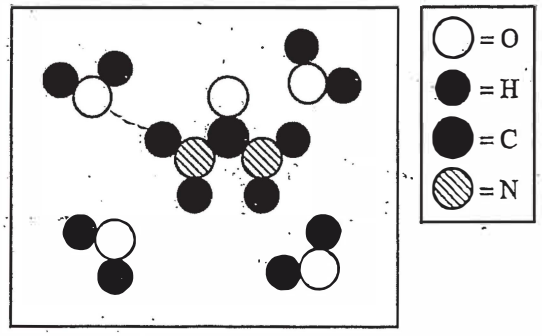


1. The compound urea, H_2NCONH_2, is widely used in chemical fertilizers. The complete Lewis electron-dot diagram for the urea molecule is shown above.

   (a) Identify the hybridization of the valence orbitals of the carbon atom in the urea molecule.

   (b) Urea has a high solubility in water, due in part to its ability to form hydrogen bonds. A urea molecule and four water molecules are represented in the box below. Draw ONE dashed line (----) to indicate a possible location of a hydrogen bond between a water molecule and the urea molecule.



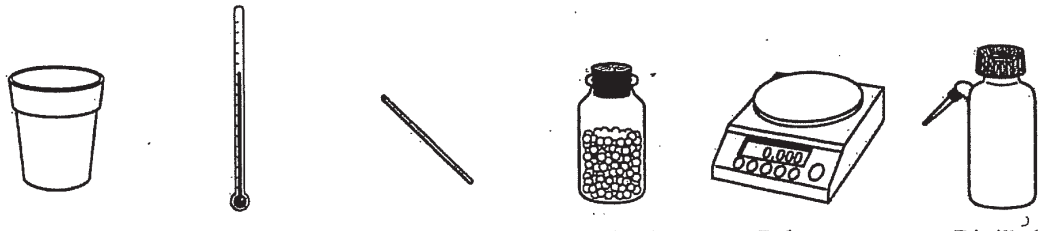
$$H_2NCONH_2(s) \rightleftarrows H_2NCONH_2(aq)$$

The dissolution of urea is represented by the equation above. A student determines that 5.39 grams of H_2NCONH_2 (molar mass 60.06 g/mol) can dissolve in water to make 5.00 mL of a saturated solution at 20.°C.

   (c) Calculate the concentration of urea, in mol/L, in the saturated solution at 20.°C.

GO ON TO THE NEXT PAGE.

(d) The student also determines that the concentration of urea in a saturated solution at 25°C is 19.8 *M*. Based on this information, is the dissolution of urea endothermic or exothermic? Justify your answer in terms of Le Chatelier's principle.



Polystyrene Cup | Thermometer | Stirring Rod | Bottle of Urea | Balance | Distilled Water

(e) The equipment shown above is provided so that the student can determine the value of the molar heat of solution for urea. Knowing that the specific heat of the solution is 4.18 J/(g·°C), list the specific measurements that are required to be made during the experiment. $q = mc\Delta T$

	$S°$ (J/(mol·K))
$H_2NCONH_2(s)$	104.6
$H_2NCONH_2(aq)$	?

(f) The entropy change for the dissolution of urea, $\Delta S°_{soln}$, is 70.1 J/(mol·K) at 25°C. Using the information in the table above, calculate the absolute molar entropy, $S°$, of aqueous urea.

(g) Using particle-level reasoning, explain why $\Delta S°_{soln}$ is positive for the dissolution of urea in water.

(h) The student claims that $\Delta S°$ for the process contributes to the thermodynamic favorability of the dissolution of urea at 25°C. Use the thermodynamic information above to support the student's claim.

a) sp^3

c) $5.39\text{ g } H_2NCONH_2 \times \frac{1\text{ mol } H_2NCONH_2}{60.06\text{ g}} = 0.0897\text{ mol } H_2NCONH_2$

$\frac{0.0897\text{ mol } H_2NCONH_2}{0.005\text{ L}} = \boxed{17.9\ \frac{\text{mol}}{\text{L}}}$

d) The dissolution of urea is exothermic. A 19.8M solution is 25°C while a 17.9M solution is 20°C, meaning that as the molarity of urea increases the temperature of the solution increases. Due to Le Chatelier's principle, ~~as~~ as urea proceeds to dissolute it releases heat to the surrounding solution thus urea is ~~endothermic~~ exothermic.

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ADDITIONAL PAGE FOR ANSWERING QUESTION 1

e) Using the balance, the mass in grams of Urea needs to be measured. Using the thermometer, the temperature in °C should be measured in the Urea saturated solution and the solution without urea. The temperature of the saturated solution is subtracted from the temperature of the Ionic solution in order to find the change in temperature. Plug in values to the formula $q=mc\Delta T$, ("c" is given) to find heat.

f) $\Delta S^\circ = \sum S^\circ_{products} - \sum S^\circ_{reactants}$ $\Delta S^\circ = 70.1\ J/(mol \cdot K)$

$H_2NCONH_2(s) \rightleftharpoons H_2NCONH_2(aq)$

104.6 ? = x

$70.1 = x - 104.6$

$+104.6 \quad +104.6$

$x = 174.7\ J/(mol \cdot K)$

g) For the reaction to be product favored, ΔS°_{soln} must be positive, due to Le Chatelier's principle.

h). Because the ΔS°_{soln} is positive, a higher temperature in the equation $\Delta G^\circ = \Delta H^\circ - T\Delta S^\circ$ means ΔG° will be negative and a negative ΔG° means the reaction proceeds to the products.

AP® CHEMISTRY
2019 SCORING COMMENTARY

Question 1

Note: Student samples are quoted verbatim and may contain spelling and grammatical errors.

Overview

Question 1 addresses multiple concepts and skills related to aqueous solutions of urea. In part (a) students are provided with a Lewis structure of urea and asked to identify the hybridization of the atomic orbitals around the carbon atom (LO 2.21; SP 1.4). Part (b) shows a particulate representation of one urea molecule with several molecules of water surrounding it. Students are asked to draw a dashed line to indicate one possible location of a hydrogen bond between a water molecule and the urea molecule (LO 2.13; SP 1.4, 6.4). Part (c) requires the calculation of the molar concentration of urea in a saturated solution (LO 3.4; SP 2.2, 5.1, 6.4). Part (d) reports that the concentration of urea in a saturated solution is higher at elevated temperature. Based on this result students are asked to predict whether the dissolution of urea is endothermic or exothermic and to explain their answer in terms of Le Chatelier's principle (LO 6.8; SP 1.4, 6.4). Part (e) shows several pieces of laboratory equipment and asks for a list of specific measurements that must be made to determine the molar heat of solution for urea (LO 5.7; SP 4.2, 5.1, 6.4).

The remainder of this question deals with the thermodynamics of the dissolution of urea. In part (f) students calculate the standard absolute entropy of aqueous urea given the standard entropy change for dissolution (ΔS°_{soln}) and the standard absolute molar entropy of solid urea (LO 5.13; SP 2.2, 6.4). By extension, part (g) asks for a particle-level explanation for why ΔS°_{soln} is positive for the dissolution of urea in water. Finally, in part (h), students explain the contribution that ΔS°_{soln} makes to the overall thermodynamic favorability of the dissolution process.

Sample: 1A
Score: 10

In part (a) the student correctly identifies the hybridization of carbon as sp^2 and earned 1 point. In part (b) the student correctly identifies a hydrogen bond between the oxygen in one water molecule and a hydrogen atom bonded to a nitrogen atom in the urea molecule. One point was earned. In part (c) the student correctly calculates the concentration of the saturated urea solution and earned 2 points. In part (d) the student correctly identifies that an increase in concentration with an increase in temperature of the urea solution indicates that the reaction will shift toward the products and concludes that the process is endothermic. The response earned 1 point. In part (e) the student listed the mass of urea, the mass of the water, the initial temperature of the water (before adding urea), and the final temperature of the water—specifically as the largest observed temperature difference—as the required measurements to be made. The response earned 2 points. In part (f) the student correctly calculates that the standard entropy of aqueous urea is 174.7 J/(mol·K). The response earned 1 point. In part (g) the student correlates an increase in entropy with increased "disorder" and attributes this to the molecules having more "positional probabilities" due to dissolution of the solid. This is acceptable and 1 point was earned. In part (h) the student indicates that a positive ΔS is necessary to overcome the positive ΔH and yield a $\Delta G^\circ < 0$, which relates to a thermodynamically favored reaction. The response earned 1 point.

Sample: 1B
Score: 8

In part (a) the student correctly identifies the hybridization of carbon as sp^2 and earned 1 point. In part (b) the student correctly identifies a hydrogen bond between a hydrogen atom in a water molecule and the oxygen atom in the urea molecule. The response earned 1 point. In part (c) the student uses an incorrect molar mass of urea to calculate the moles but then performs the calculation of the concentration correctly using that value, so 1 point was earned. In part (d) the student correctly concludes that the increase in urea concentration with increased

Question 1 (continued)

temperature implies that the equilibrium "system shifts right" indicating an endothermic process. The response earned 1 point. In part (e) the student lists only the mass of the urea, but lists the temperature of the water and the solution, implying initial and final temperature measurements. One point was earned. In part (f) the student correctly calculates that the standard entropy of aqueous urea is 174.7 J/(mol ·K) and earned 1 point. In part (g) the student describes how there is more "chaos and disorder" between particles of the "liquid" (understood as the liquid water of the aqueous solution) compared to the solid and earned 1 point. In part (h) the student indicates that the positive $\Delta S°$ value is necessary for ΔG to be less than zero at higher temperatures and concludes that the $\Delta S°$ is "thermodynamically favorable" as a result; thus 1 point was earned.

Sample: 1C
Score: 6

In part (a) the student incorrectly identifies the hybridization of carbon as sp^3. No point was earned. In part (b) the student correctly identifies a hydrogen bond between an oxygen atom in a water molecule and a hydrogen atom in the urea molecule and earned 1 point. In part (c) the student correctly calculates the concentration of the urea and earned 2 points. In part (d) no point was earned. The student indicates that the process is exothermic, despite an effective description of what would be observed during the temperature increase of an *endothermic* dissolution process. In part (e) the student says to measure the temperature of a "solution without urea" and the temperature of the "urea saturated solution." This is equivalent to the initial temperature and the final temperature of the process. However, only the mass of urea is indicated by the student, so 1 point was earned. In part (f) the student correctly calculates the standard entropy of aqueous urea as 174.7 J/(mol ·K) and earned 1 point. In part (g) no point was earned. The student incorrectly uses Le Châtelier's principle to justify the increase in entropy for the process. In part (h) the student relates the positive value of $\Delta S°$ to obtaining a negative $\Delta G°$, which contributes to the thermodynamic favorability; thus, 1 point was earned.