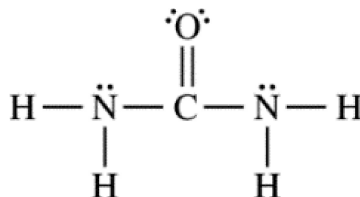


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**Question 1**

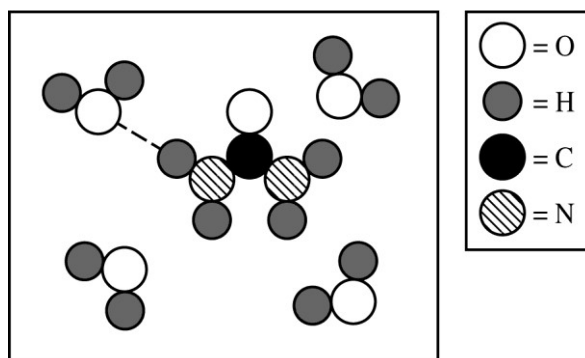


The compound urea,  $\text{H}_2\text{NCONH}_2$ , is widely used in chemical fertilizers. The complete Lewis electron-dot diagram for the urea molecule is shown above.

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

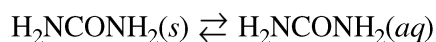
$sp^2$	1 point is earned for the correct answer.
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- (b) Urea has a high solubility in water, due in part to its ability to form hydrogen bonds. A urea molecule and four water molecules are represented in the box below. Draw ONE dashed line (---) to 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.



The dissolution of urea is represented by the equation above. A student determines that 5.39 grams of  $\text{H}_2\text{NCONH}_2$  (molar mass 60.06 g/mol) can dissolve in water to make 5.00 mL of a saturated solution at 20.°C.

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**Question 1 (continued)**

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

$5.39 \text{ g H}_2\text{NCONH}_2 \times \frac{1 \text{ mol}}{60.06 \text{ g}} = 0.0897 \text{ mol}$ $\frac{0.0897 \text{ mol}}{0.00500 \text{ L}} = 17.9 \text{ M}$	1 point is earned for the correct number of moles of urea (may be implicit).  1 point is earned for the correct molarity.
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(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.
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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.

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.
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**Question 1 (continued)**

	$S^\circ$ (J/(mol·K))
$\text{H}_2\text{NCONH}_2(s)$	104.6
$\text{H}_2\text{NCONH}_2(aq)$	?

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

$\Delta S_{soln}^\circ = S^\circ(\text{H}_2\text{NCONH}_2(aq)) - S^\circ(\text{H}_2\text{NCONH}_2(s))$ $70.1 \text{ J/(mol}\cdot\text{K)} = S^\circ(\text{H}_2\text{NCONH}_2(aq)) - 104.6 \text{ J/(mol}\cdot\text{K)}$ $S^\circ(\text{H}_2\text{NCONH}_2(aq)) = 174.7 \text{ J/(mol}\cdot\text{K)}$	1 point is earned for the correct answer.
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(g) Using particle-level reasoning, explain why  $\Delta S_{soln}^\circ$  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 $\Delta S_{soln}^\circ$ .	1 point is earned for a correct explanation.
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(h) The student claims that  $\Delta S^\circ$  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 $\Delta G^\circ$ , with $\Delta G^\circ = \Delta H^\circ - T\Delta S^\circ$ . Since $\Delta S^\circ$ is positive, the $T\Delta S^\circ$ term makes the value of $\Delta G^\circ$ smaller and thus makes the dissolution more thermodynamically favorable.	1 point is earned for the correct answer.
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