

AP[®] CHEMISTRY
2011 SCORING GUIDELINES (Form B)

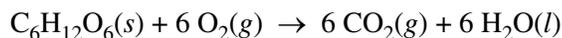
Question 3
(9 points)

Answer the following questions about glucose, $C_6H_{12}O_6$, an important biochemical energy source.

(a) Write the empirical formula of glucose.

CH_2O	1 point is earned for the correct formula.
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In many organisms, glucose is oxidized to carbon dioxide and water, as represented by the following equation.

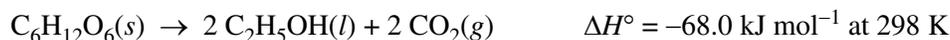


A 2.50 g sample of glucose and an excess of $O_2(g)$ were placed in a calorimeter. After the reaction was initiated and proceeded to completion, the total heat released by the reaction was calculated to be 39.0 kJ.

(b) Calculate the value of ΔH° , in kJ mol^{-1} , for the combustion of glucose.

$2.50 \text{ g} \times \frac{1 \text{ mol } C_6H_{12}O_6}{180.16 \text{ g } C_6H_{12}O_6} = 0.0139 \text{ mol } C_6H_{12}O_6$ $\frac{-39.0 \text{ kJ}}{0.0139 \text{ mol}} = -2,810 \text{ kJ mol}^{-1}$	1 point is earned for the correct answer.
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(c) When oxygen is not available, glucose can be oxidized by fermentation. In that process, ethanol and carbon dioxide are produced, as represented by the following equation.



The value of the equilibrium constant, K_p , for the reaction at 298 K is 8.9×10^{39} .

(i) Calculate the value of the standard free-energy change, ΔG° , for the reaction at 298 K. Include units with your answer.

$\Delta G^\circ = -RT \ln K$ $= -(8.31 \text{ J mol}^{-1} \text{ K}^{-1})(298 \text{ K})(\ln 8.9 \times 10^{39})$ $= -228,000 \text{ J mol}^{-1} = -228 \text{ kJ mol}^{-1}$	1 point is earned for correct setup. 1 point is earned for correct answer.
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AP[®] CHEMISTRY
2011 SCORING GUIDELINES (Form B)

Question 3 (continued)

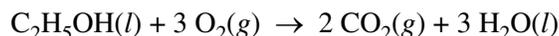
(ii) Calculate the value of the standard entropy change, ΔS° , in $\text{J K}^{-1} \text{mol}^{-1}$, for the reaction at 298 K.

$\Delta G^\circ = \Delta H^\circ - T\Delta S^\circ$ $\Delta S^\circ = \frac{\Delta H^\circ - \Delta G^\circ}{T}$ $= \frac{(-68.0 \text{ kJ mol}^{-1}) - (-228 \text{ kJ mol}^{-1})}{298 \text{ K}}$ $= 0.537 \text{ kJ K}^{-1} \text{ mol}^{-1} = 537 \text{ J K}^{-1} \text{ mol}^{-1}$	<p>1 point is earned for the correct setup.</p> <p>1 point is earned for the correct answer.</p>
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(iii) Indicate whether the equilibrium constant for the fermentation reaction increases, decreases, or remains the same if the temperature is increased. Justify your answer.

<p>ΔH° is negative, so when the temperature increases, the equilibrium for the reaction is shifted to the left (according to Le Châtelier's principle). This means that the equilibrium constant decreases.</p>	<p>1 point is earned for the correct answer with justification.</p>
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(d) Using your answer for part (b) and the information provided in part (c), calculate the value of ΔH° for the following reaction.



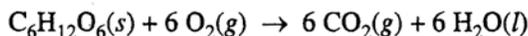
$\text{C}_6\text{H}_{12}\text{O}_6(s) + 6 \text{O}_2(g) \rightarrow 6 \text{CO}_2(g) + 6 \text{H}_2\text{O}(l) \quad \Delta H^\circ = -2,810 \text{ kJ mol}^{-1}$ $2 \text{C}_2\text{H}_5\text{OH}(l) + 2 \text{CO}_2(g) \rightarrow \text{C}_6\text{H}_{12}\text{O}_6(s) \quad \Delta H^\circ = 68.0 \text{ kJ mol}^{-1}$ <hr style="width: 50%; margin: 10px auto;"/> $2 \text{C}_2\text{H}_5\text{OH}(l) + 6 \text{O}_2(g) \rightarrow 4 \text{CO}_2(g) + 6 \text{H}_2\text{O}(l) \quad \Delta H^\circ = -2,740 \text{ kJ mol}^{-1},$ <p>thus ΔH° for the reaction as written in (d) is $-1,370 \text{ kJ mol}^{-1}$.</p>	<p>1 point is earned for the correct setup.</p> <p>1 point is earned for the correct answer.</p>
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3. Answer the following questions about glucose, $C_6H_{12}O_6$, an important biochemical energy source.

3A₁

(a) Write the empirical formula of glucose.

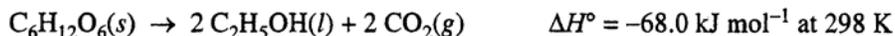
In many organisms, glucose is oxidized to carbon dioxide and water, as represented by the following equation.



A 2.50 g sample of glucose and an excess of $O_2(g)$ were placed in a calorimeter. After the reaction was initiated and proceeded to completion, the total heat released by the reaction was calculated to be 39.0 kJ.

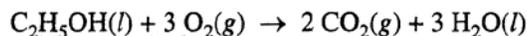
(b) Calculate the value of ΔH° , in kJ mol^{-1} , for the combustion of glucose.

(c) When oxygen is not available, glucose can be oxidized by fermentation. In that process, ethanol and carbon dioxide are produced, as represented by the following equation.



The value of the equilibrium constant, K_p , for the reaction at 298 K is 8.9×10^{39} .

- (i) Calculate the value of the standard free-energy change, ΔG° , for the reaction at 298 K. Include units with your answer.
- (ii) Calculate the value of the standard entropy change, ΔS° , in $\text{J K}^{-1} \text{ mol}^{-1}$, for the reaction at 298 K.
- (iii) Indicate whether the equilibrium constant for the fermentation reaction increases, decreases, or remains the same if the temperature is increased. Justify your answer.
- (d) Using your answer for part (b) and the information provided in part (c), calculate the value of ΔH° for the following reaction.



a) CH_2O

b) i) $\text{mol glucose} = \frac{2.5 \text{ g}}{180 \text{ g} \cdot \text{mol}^{-1}} = 0.0139 \text{ mol}$

ii) $\Delta H^\circ (\text{kJ mol}^{-1}) = \frac{\Delta H}{0.0139 \text{ mol}} = \frac{-39 \text{ kJ}}{0.0139}$ * (heat released $\Rightarrow \Delta H < 0$)

$= -2806 \text{ kJ mol}^{-1}$

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VERING QUESTION 3

$$c) i) \Delta G^\circ = -RT \ln K_p$$

$$\Rightarrow \Delta G^\circ = -8.31 \times 298 \times \ln(8.9 \times 10^{39})$$

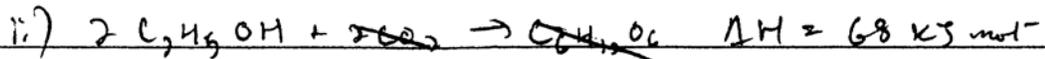
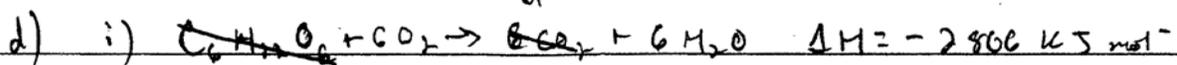
$$= -2.3 \times 10^5 \text{ J mol}^{-1}$$

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

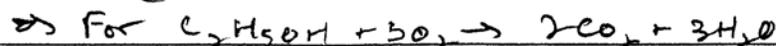
$$\Rightarrow -2.3 \times 10^5 \text{ J mol}^{-1} = -6.8 \times 10^4 \text{ J mol}^{-1} - 298 (\Delta S^\circ)$$

$$\Rightarrow \Delta S^\circ = \frac{-2.3 \times 10^5 + 6.8 \times 10^4}{-298} = 5.4 \times 10^2 \text{ J K}^{-1} \text{ mol}^{-1}$$

iii) The equilibrium constant will decrease if the temperature is increased due to Le Chatelier's principle; the reaction is exothermic, thus it will increase the temperature. If the temperature is externally increased, the products will absorb energy, and the reverse reaction occurs.



$$\Delta H = (-2806 + 68) \text{ kJ mol}^{-1} = -2738 \text{ kJ mol}^{-1}$$



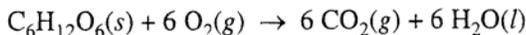
$$\Delta H = \frac{-2738}{2} = -1369 \text{ kJ mol}^{-1}$$

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3. Answer the following questions about glucose, C₆H₁₂O₆, an important biochemical energy source.

(a) Write the empirical formula of glucose.

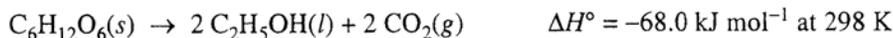
In many organisms, glucose is oxidized to carbon dioxide and water, as represented by the following equation.



A 2.50 g sample of glucose and an excess of O₂(g) were placed in a calorimeter. After the reaction was initiated and proceeded to completion, the total heat released by the reaction was calculated to be 39.0 kJ.

(b) Calculate the value of ΔH°, in kJ mol⁻¹, for the combustion of glucose.

(c) When oxygen is not available, glucose can be oxidized by fermentation. In that process, ethanol and carbon dioxide are produced, as represented by the following equation.



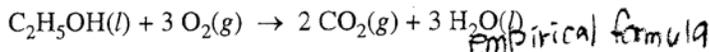
The value of the equilibrium constant, K_p, for the reaction at 298 K is 8.9 × 10³⁹.

(i) Calculate the value of the standard free-energy change, ΔG°, for the reaction at 298 K. Include units with your answer.

(ii) Calculate the value of the standard entropy change, ΔS°, in J K⁻¹ mol⁻¹, for the reaction at 298 K.

(iii) Indicate whether the equilibrium constant for the fermentation reaction increases, decreases, or remains the same if the temperature is increased. Justify your answer.

(d) Using your answer for part (b) and the information provided in part (c), calculate the value of ΔH° for the following reaction.



(a) molecular formula: C₆H₁₂O₆ $\xrightarrow{\text{divide by 6}}$ C₁H₂O₁

∴ Empirical formula of glucose is CH₂O.

(b) The number of moles of glucose: $2.5 / 180 \hat{=}$ 0.0139 mol

$$\Delta H^\circ = \frac{\text{the total heat released}}{\text{the number of moles of glucose}} = \frac{-39.0 \text{ kJ}}{0.0139 \text{ mol}} = -2.81 \times 10^3 \text{ kJ/mol}$$

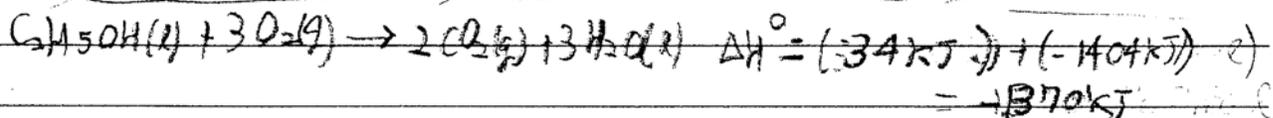
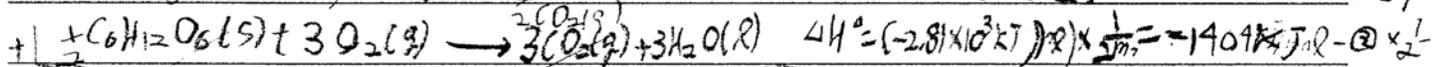
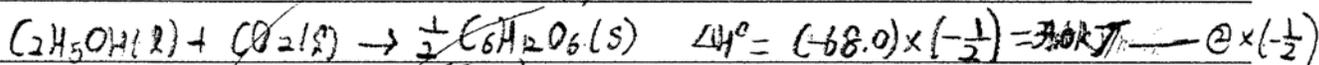
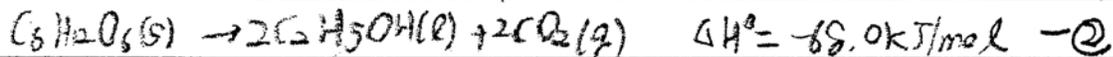
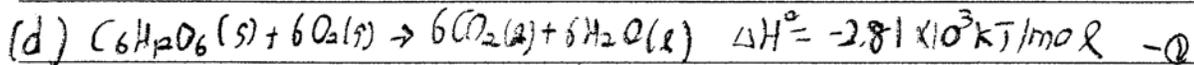
(c) (i) $\Delta G^\circ = -RT \ln K_p = -(8.31)(298) \ln(8.9 \times 10^{39}) = -228 \text{ kJ/mol}$

(ii) $\Delta G^\circ = \Delta H^\circ - T\Delta S^\circ \quad \Delta S^\circ = \frac{\Delta G^\circ - \Delta H^\circ}{T} = \frac{(-228 \text{ kJ/mol}) - (-68.0 \text{ kJ/mol})}{(298 \text{ K})} = -536 \text{ J/mol}\cdot\text{K}$

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$$(iii) \Delta G^\circ = \Delta H^\circ - T\Delta S^\circ \quad (\Delta H^\circ < 0, \Delta S^\circ < 0) \rightarrow (T \uparrow \rightarrow \Delta G^\circ \uparrow)$$

if the temperature is increased, $-T\Delta S^\circ$ will increase to positive so ΔG° becomes greater (to positive) and the equilibrium constant for the fermentation reaction decreases (if the temperature is increased). ($\Delta G^\circ = -RT \ln K$)



\therefore The value of ΔH° for the following reaction is -1370 kJ

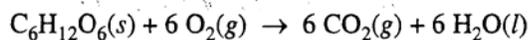
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3. Answer the following questions about glucose, $C_6H_{12}O_6$, an important biochemical energy source.

3C₁

(a) Write the empirical formula of glucose.

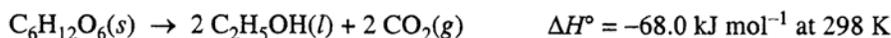
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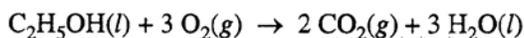
(b) Calculate the value of ΔH° , in kJ mol^{-1} , for the combustion of glucose.

(c) When oxygen is not available, glucose can be oxidized by fermentation. In that process, ethanol and carbon dioxide are produced, as represented by the following equation.



The value of the equilibrium constant, K_p , for the reaction at 298 K is 8.9×10^{39} .

- Calculate the value of the standard free-energy change, ΔG° , for the reaction at 298 K. Include units with your answer.
 - Calculate the value of the standard entropy change, ΔS° , in $\text{J K}^{-1} \text{ mol}^{-1}$, for the reaction at 298 K.
 - Indicate whether the equilibrium constant for the fermentation reaction increases, decreases, or remains the same if the temperature is increased. Justify your answer.
- (d) Using your answer for part (b) and the information provided in part (c), calculate the value of ΔH° for the following reaction.



Ⓑ $\Delta H^\circ = \frac{39 \text{ kJ}}{5 \text{ mol}} = 7.8 \text{ kJ/mol}$

Ⓒ (i) $\Delta G^\circ = -RT \ln K = -(8.31 \text{ J/mol}\cdot\text{K})(298 \text{ K}) \ln(8.9 \times 10^{39})$
 $= -227. \text{ kJ/mol}$

(ii) $\Delta G^\circ = \Delta H^\circ - T\Delta S^\circ$

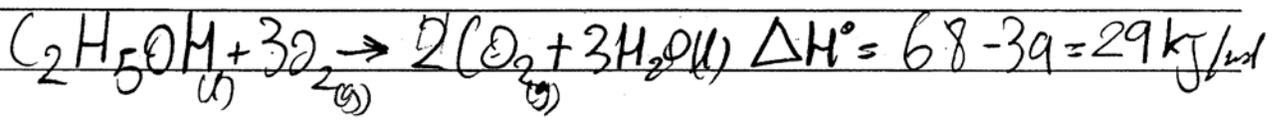
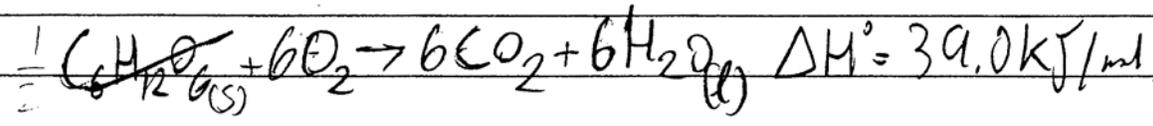
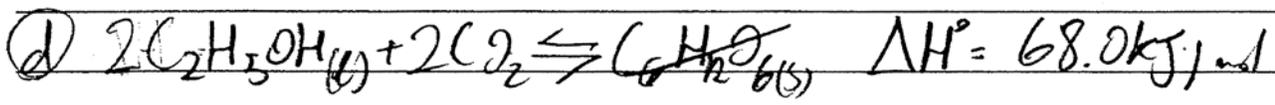
$-227 = -68 - (298)\Delta S^\circ$

$\Delta S^\circ = \frac{-227 + 68}{298} = 534 \text{ J/K}\cdot\text{mol}$

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FINAL PAGE FOR ANSWERING QUESTION 3

(iii) It increases because the increase in heat will favor the product thus creating more moles of the products, the reaction is exothermic.



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AP[®] CHEMISTRY
2011 SCORING COMMENTARY (Form B)

Question 3

Sample: 3A

Score: 9

This response earned all 9 possible points. Part (a) earned 1 point for showing the correct empirical formula for glucose. Part (b) earned 1 point for correctly determining the number of moles of glucose in the 2.50 gram sample and the subsequent calculation of the value for the ΔH° . Part (c) earned 5 points: 1 point in part (c)(i) for the correct setup and 1 point for calculating the correct answer; 1 point in part (c)(ii) for the correct setup and 1 point for calculating the correct answer; and 1 point in part (c)(iii) for correctly focusing on whether the reaction is exothermic or endothermic and for reaching the correct conclusion about the change in the value of the equilibrium constant. Part (d) earned 2 points for showing the proper equations in their correct orientation and dividing the resulting ΔH° value by 2 to get to the correct answer.

Sample: 3B

Score: 7

Part (c)(ii) earned 1 point for the correct initial equation and setup, but the final answer has an incorrect negative sign so the second point was not earned. Part (c)(iii) did not earn the point as the response incorrectly attempts to show how the value of ΔG° would change when the temperature increases, and use of the equation $\Delta G^\circ = \Delta H^\circ - T\Delta S^\circ$ requires constant temperature.

Sample: 3C

Score: 5

Part (b) did not earn the point because ΔH° is calculated incorrectly. Part (c)(iii) did not earn the point because of the incorrect conclusion. No points were earned in part (d) because the value for the ΔH° used in the second equation is neither the correct value nor the value calculated in part (b). Also, although the coefficients in the final equation are divided by 2, the value of the reaction's ΔH° is not.