AP® Chemistry (Operational)
2004 Sample Student Responses

2A 1

Answer EITHER Question 2 below OR Question 3 printed on page 16. Only one of these two questions will be graded. If you start both questions, be sure to cross out the question you do not want graded. The Section II score weighting for the question you choose is 20 percent.

$$\overset{1.34\,mol}{2\,Fe(s)} + \overset{1.25\,mol}{\tfrac{3}{2}\,O_2(g)} \rightarrow Fe_2O_3(s) \qquad \Delta H_f^\circ = -824\text{ kJ mol}^{-1}$$

2. Iron reacts with oxygen to produce iron(III) oxide, as represented by the equation above. A 75.0 g sample of $Fe(s)$ is mixed with 11.5 L of $O_2(g)$ at 2.66 atm and 298 K.

(a) Calculate the number of moles of each of the following before the reaction begins.

(i) $Fe(s)$

(ii) $O_2(g)$

(b) Identify the limiting reactant when the mixture is heated to produce $Fe_2O_3(s)$. Support your answer with calculations.

(c) Calculate the number of moles of $Fe_2O_3(s)$ produced when the reaction proceeds to completion.

(d) The standard free energy of formation, ΔG_f°, of $Fe_2O_3(s)$ is $-740.$ kJ mol^{-1} at 298 K.

(i) Calculate the standard entropy of formation, ΔS_f°, of $Fe_2O_3(s)$ at 298 K. Include units with your answer.

(ii) Which is more responsible for the spontaneity of the formation reaction at 298 K, the standard enthalpy of formation, ΔH_f°, or the standard entropy of formation, ΔS_f°? Justify your answer.

The reaction represented below also produces iron(III) oxide. The value of ΔH° for the reaction is $-280.$ kJ per mole of $Fe_2O_3(s)$ formed.

$$2\,FeO(s) + \tfrac{1}{2}\,O_2(g) \rightarrow Fe_2O_3(s)$$

(e) Calculate the standard enthalpy of formation, ΔH_f°, of $FeO(s)$.

(a)(i) $\dfrac{75.0\text{ g Fe}}{55.85\ \frac{g}{mol}} = 1.34\text{ mol Fe}$

(ii) $PV = nRT$

$n = \dfrac{PV}{RT}$

$n = \dfrac{(2.66\text{ atm})(11.5\text{ L})}{(.0821\ \frac{L\,atm}{K\,mol})(298\text{ K})}$

$n = 1.25\text{ mol }O_2$

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(b) $\frac{\frac{3}{2} \text{ mol } O_2}{2 \text{ mol Fe}} = \frac{1.25 \text{ mol } O_2}{x \text{ mol Fe}}$ $\frac{\frac{3}{2} \text{ mol } O_2}{2 \text{ mol Fe}} = \frac{x \text{ mol } O_2}{1.34 \text{ mol Fe}}$

$x = 1.67 \text{ mol Fe}$ $x = 1.01 \text{ mol } O_2$

More oxygen than neccessary → only 1.01 mol O_2 needed.
Fe is the limiting reactant.

(c) $\frac{2 \text{ mol Fe}}{1 \text{ mol } Fe_2O_3} = \frac{1.34 \text{ mol Fe}}{X \text{ mol } Fe_2O_3}$

$x = .670 \text{ mol } Fe_2O_3$

(d) $\Delta G^\circ_f = \Delta H^\circ_f - T\Delta S^\circ_f$

(i) $\Delta S^\circ_f = \frac{\Delta H^\circ_f - \Delta G^\circ_f}{T}$

$= \frac{-824. \frac{kJ}{mol} - \left(-740. \frac{kJ}{mol}\right)}{298 \text{ K}}$

$\Delta S^\circ_f = -.282 \frac{kJ}{K \cdot mol}$

(ii) A reaction can be spontaneous if either its ΔH° is negative or its ΔS° is positive. In this reaction, the $\Delta H^\circ < 0$ + $\Delta S^\circ < 0$. Therefore the ΔH° contributes most to the spontaneity of the reaction ($\Delta G^\circ < 0$).

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

(e) $2FeO + \frac{1}{2}O_2 \rightarrow Fe_2O_3$ $\Delta H^\circ = -280 \frac{kJ}{mol}$

$1(\Delta H^\circ_f\ Fe_2O_3) - 2(\Delta H^\circ_f\ FeO) = -280 \frac{kJ}{mol}$

$\left(-824 \frac{kJ}{mol}\right) - 2x = -280 \text{ kJ/mol}$

$-2x = 544 \text{ kJ/mol}$

$x = -272 \frac{kJ}{mol}$

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2B, 1

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$$2\,Fe(s) + \frac{3}{2}\,O_2(g) \rightarrow Fe_2O_3(s) \qquad \Delta H_f^\circ = -824\ \text{kJ mol}^{-1}$$

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   (e) Calculate the standard enthalpy of formation, ΔH_f°, of $FeO(s)$.

a) i) Fe(s) $75g\,Fe(s) \cdot \frac{1\,mol\,Fe}{55.85g\,Fe} = \boxed{1.34\ mol\ Fe}$

~~b~~ ii) $11.5L\,O_2 \cdot \frac{1\,mol\,O_2}{22.4L\,O_2} = \boxed{.513\,mol\,O_2}$

b) $\frac{Fe(s)}{O_2(g)} = \frac{2}{\frac{3}{2}} = 2 \cdot \frac{2}{3} = \frac{4}{3} = \frac{1.333\,mol\,Fe}{1\,mol\,O_2}$

$\frac{1.34\,mol\,Fe}{.513\,mol\,O_2} = \frac{2.6157\,mol\,Fe}{1\,mol\,O_2}$

Since ~~2.6~~ $\frac{4}{3} < \frac{2.6157}{1}$, $\boxed{O_2 \text{ is the limiting reactant}}$

(There's more than enough Fe(s))

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c) Hence, $.513 \text{ mol } O_2 \cdot \frac{1 \text{ mol } Fe_2O_3}{\frac{3}{2} \text{ mol } O_2} = \boxed{.342 \text{ mol } Fe_2O_3}$

d) $\Delta G^\circ_f \; Fe_2O_3 = -740 \text{ kJ/mol}$

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

$-740 \text{ kJ/mol} = -824 \text{ kJ/mol} - 298\text{K}(\Delta S^\circ_f)$

$84 \text{ kJ/mol} = -298\text{K}(\Delta S^\circ_f)$

$\boxed{\Delta S^\circ_f = -.282 \text{ kJ/mol}\cdot\text{K}}$

ii) If you examine both values, it is clear that one dominates the other.

$\Delta H^\circ_f = -824 \text{ kJ/mol}$ $\qquad -T\Delta S = 84 \text{ kJ/mol}$

Clearly, ΔH°_f is the larger value, and ~~of~~ thus the standard enthalpy of formation is responsible for the ~~sponaity~~ spontaneity of the reaction. ΔS°_f is far too small ($-.282$ kJ/mol K) to be a significant factor.

e) $2FeO(s) + \frac{1}{2}O_2(g) \rightarrow Fe_2O_3(s)$

$\Delta H^\circ \; Fe_2O_3 = -280 \text{ kJ/mol}$ $\qquad \Delta H^\circ_f \; Fe_2O_3 = -824 \text{ kJ/mol}$

$\Delta H^\circ_f \; FeO = ?$

$\Delta H^\circ = \Sigma \Delta H^\circ_f \text{ products} - \Sigma \Delta H^\circ_f \text{ reactants}$

$-280 \text{ kJ/mol} = -824 \text{ kJ/mol} - [2(\Delta H^\circ_f FeO) + \frac{1}{2}(\Delta H^\circ_f O_2)]$

Since $\Delta H^\circ_f O_2 = 0$,

$-280 \text{ kJ/mol} = -824 \text{ kJ/mol} - 2(\Delta H^\circ_f FeO)$

$544 \text{ kJ/mol} = -2(\Delta H^\circ_f FeO)$

$\boxed{-272. \text{ kJ/mol} = \Delta H^\circ_f FeO}$

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2C 1

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$$2\,Fe(s) + \frac{3}{2}\,O_2(g) \rightarrow Fe_2O_3(s) \qquad \Delta H_f^\circ = -824 \text{ kJ mol}^{-1}$$

4 3 2 1648

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$$2\,FeO(s) + \frac{1}{2}\,O_2(g) \rightarrow Fe_2O_3(s) \qquad Fe_2O_3 \rightarrow \frac{1}{2}O_2 + 2FeO$$

(e) Calculate the standard enthalpy of formation, ΔH_f°, of $FeO(s)$.

a. i. Fe 1,34 moles

ii. O_2 $\quad 2.66(11.5) = n(.0821)(298)$

$n = 1.25$ moles

b. $1.34 \times \left(\frac{3/2}{2}\right) = 1.005$ moles O_2 needed Fe is limiting

$1.25 \times \left(\frac{2}{3/2}\right) = 1.66$ moles Fe needed

c. $1.34 \times \left(\frac{1}{2}\right) = .67$ moles Fe_2O_3

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ADDITIONAL PAGE FOR ANSWERING QUESTION 2.

d. i $\Delta G = \Delta H - T\Delta S$

$-1480000 = -824000 - (298)\Delta S$

$-656000 = -298\Delta S$

$\Delta S = 2201$ J/mol · K

ii. Standard entropy of formation is more responsible because it is a measure of the order of the reaction. It tells whether or not the reaction is orderly or chaotic.

e. $\frac{-(-280)}{2} = 140$ kJ/mol

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