AP® CHEMISTRY
2011 SCORING GUIDELINES

Question 3

Hydrogen gas burns in air according to the equation below.

$$2\ H_2(g) + O_2(g) \rightarrow 2\ H_2O(l)$$

(a) Calculate the standard enthalpy change, ΔH°_{298}, for the reaction represented by the equation above.

(The molar enthalpy of formation, ΔH°_f, for $H_2O(l)$ is -285.8 kJ mol^{-1} at 298 K.)

$\Delta H^\circ_{298} = [2\ (-285.8)] - [2(0) + 1(0)] = -571.6$ kJ mol^{-1}	1 point is earned for the correct answer.

(b) Calculate the amount of heat, in kJ, that is released when 10.0 g of $H_2(g)$ is burned in air.

$q = 10\ \text{g}\ H_2 \times \frac{1\ \text{mol}\ H_2}{2.016\ \text{g}\ H_2} \times \frac{285.8\ \text{kJ}}{1\ \text{mol}\ H_2} = 1.42 \times 10^3\ \text{kJ}$	1 point is earned for the correct setup. 1 point is earned for the correct answer.

(c) Given that the molar enthalpy of vaporization, ΔH°_{vap}, for $H_2O(l)$ is 44.0 kJ mol^{-1} at 298 K, what is the standard enthalpy change, ΔH°_{298}, for the reaction $2\ H_2(g) + O_2(g) \rightarrow 2\ H_2O(g)$?

$2\ H_2(g) + O_2(g) \rightarrow 2\ H_2O(l)$ $\quad -571.6$ kJ $2\ H_2O(l) \rightarrow 2\ H_2O(g)$ $\quad +2(44.0)$ kJ $2\ H_2(g) + O_2(g) \rightarrow 2\ H_2O(g)$ $\quad -483.6$ kJ	1 point is earned for the correct answer.

A fuel cell is an electrochemical cell that converts the chemical energy stored in a fuel into electrical energy. A cell that uses H_2 as the fuel can be constructed based on the following half-reactions.

Half-reaction	E° (298 K)
$2\ H_2O(l) + O_2(g) + 4\ e^- \rightarrow 4\ OH^-(aq)$	0.40 V
$2\ H_2O(l) + 2\ e^- \rightarrow H_2(g) + 2\ OH^-(aq)$	-0.83 V

Question 3 (continued)

(d) Write the equation for the overall cell reaction.

$2\ H_2O(l) + O_2(g) + 4\ e^- \rightarrow 4\ OH^-(aq)$ $2\ H_2(g) + 4\ OH^-(aq) \rightarrow 4\ H_2O(l) + 4\ e^-$ $2\ H_2(g) + O_2(g) \rightarrow 2\ H_2O(l)$	1 point is earned for the correct equation.

(e) Calculate the standard potential for the cell at 298 K.

$E^\circ = 0.40\ V - (-0.83\ V) = 1.23\ V$	1 point is earned for the correct answer.

(f) Assume that 0.93 mol of $H_2(g)$ is consumed as the cell operates for 600. seconds.

(i) Calculate the number of moles of electrons that pass through the cell.

$0.93\ mol\ H_2 \times \frac{2\ mol\ e^-}{1\ mol\ H_2} = 1.9\ mol\ e^-$	1 point is earned for the correct answer.

(ii) Calculate the average current, in amperes, that passes through the cell.

$1.9\ mol\ e^- \times \frac{96{,}500\ C}{1\ mol\ e^-} = 1.8 \times 10^5\ C$ $I = \frac{q}{t} = \frac{1.8 \times 10^5\ C}{600.\ s} = 3.0 \times 10^2\ amps$	1 point is earned for calculation of the charge in coulombs. 1 point is earned for calculation of the current in amperes.

(g) Some fuel cells use butane gas, C_4H_{10}, rather than hydrogen gas. The overall reaction that occurs in a butane fuel cell is $2\ C_4H_{10}(g) + 13\ O_2(g) \rightarrow 8\ CO_2(g) + 10\ H_2O(l)$. What is one environmental advantage of using fuel cells that are based on hydrogen rather than on hydrocarbons such as butane?

Hydrogen fuel cells produce only water as a product, unlike fuel cells that use hydrocarbons, which release carbon dioxide. Carbon dioxide contributes to global warming via the enhanced atmospheric greenhouse effect.	1 point is earned for an acceptable environmental advantage.