Consider the following information.

<table>
<thead>
<tr>
<th>Reaction</th>
<th>Enthalpy of reaction</th>
</tr>
</thead>
<tbody>
<tr>
<td>3C(s) + 4 H(_2)(g) → C(_3)H(_8)(g)</td>
<td>x</td>
</tr>
<tr>
<td>C(s) + O(_2)(g) → CO(_2)(g)</td>
<td>y</td>
</tr>
<tr>
<td>H(_2)(g) + 1/2 O(_2)(g) → H(_2)O(ℓ)</td>
<td>z</td>
</tr>
</tbody>
</table>

Based on the information above, which expression gives the heat of combustion, \(\Delta H_{comb}\), for propane, C\(_3\)H\(_8\)?

\[
C\(_3\)H\(_8\)(g) + 5 O\(_2\)(g) → 3 CO\(_2\)(g) + 4 H\(_2\)O(ℓ)
\]

a. \(x - (y + z)\)  
b. \((y + z) + x\)  
c. \(x + (3y + 4z)\)  
d. \(x - (3y + 4z)\)

determine \(\Delta H^\circ_{rxn}\) for the following reaction,

\[
N\(_2\)(g) + 3 H\(_2\)(g) → 2 NH\(_3\)(g)
\]

given the thermochemical equations below.

\[
\begin{align*}
N\(_2\)(g) + O\(_2\)(g) → 2 NO(g) & \quad \Delta H = +180.8 \text{ kJ} -1 \\
4 NH\(_3\)(g) + 5 O\(_2\)(g) → 4 NO(g) + 6 H\(_2\)O(g) & \quad \Delta H = -906.2 \text{ kJ} \\
2 H\(_2\)(g) + O\(_2\)(g) → 2 H\(_2\)O(ℓ) & \quad \Delta H = -483.6 \text{ kJ} \\
\end{align*}
\]

a. -1209.0 kJ  
b. -1189.0 kJ  
c. -756.5 kJ  
d. -91.5 kJ

What is the standard enthalpy change, \(\Delta H^\circ_{rxn}\), for the reaction represented above?

\[
\Delta H^\circ_f\text{ of } C\(_3\)H\(_8\)(g) \text{ is } 230 \text{ kJ mol}^{-1} ; \quad \Delta H^\circ_f\text{ of } C_6H_{12}(g) \text{ is } 83 \text{ kJ mol}^{-1}.
\]

a. -607 kJ  
b. -147 kJ  
c. -19 kJ  
d. +19 kJ
\[ \text{CH}_4(g) + 2 \text{O}_2(g) \rightarrow \text{CO}_2(g) + 2 \text{H}_2\text{O}(\ell) \quad \Delta H^\circ_{\text{rxn}} = -889.1 \text{ kJ} \]

\[ \Delta H_f \text{H}_2\text{O}(l) = -285.8 \text{ kJ/mol} \]

\[ \Delta H_f \text{CO}_2(g) = -393.3 \text{ kJ/mol} \]

4. What is the standard heat of formation of methane, CH\(_4\)(g), as calculated from the data above?

   a. -210.0 kJ/mole
   b. -107.5 kJ/mole
   c. -75.8 kJ/mole
   d. 75.8 kJ/mole

5. Calculate \( \Delta H^\circ_{\text{rxn}} \) for the combustion of gaseous ethanol,

\[ \text{C}_2\text{H}_5\text{OH}(g) + 3 \text{O}_2(g) \rightarrow 2 \text{CO}_2(g) + 3 \text{H}_2\text{O}(g) \]

using standard molar enthalpies of formation.

<table>
<thead>
<tr>
<th>molecule</th>
<th>( \Delta H^\circ_f ) (kJ/mol)</th>
</tr>
</thead>
<tbody>
<tr>
<td>\text{C}_2\text{H}_5\text{OH}(g)</td>
<td>-235.3</td>
</tr>
<tr>
<td>\text{CO}_2(g)</td>
<td>-393.5</td>
</tr>
<tr>
<td>\text{H}_2\text{O}(g)</td>
<td>-241.8</td>
</tr>
</tbody>
</table>

   a. -1747.7 kJ
   b. -1277.1 kJ
   c. -793.5 kJ
   d. -400.0 kJ

6. When 27.0 g of an unknown metal at 88.4 °C is placed in 115 g H\(_2\)O at 21.0 °C, the final temperature of the water is 23.7 °C. What is the specific heat capacity of the metal? The specific heat capacity of water is 4.184 J/g·K.

   a. 0.34 J/g·K
   b. 0.51 J/g·K
   c. 0.74 J/g·K
   d. 0.94 J/g·K

7. The thermochemical equation for the combustion of hexane is shown below.

\[ \text{C}_6\text{H}_{14}(g) + \frac{19}{2} \text{O}_2(g) \rightarrow 6 \text{CO}_2(g) + 7 \text{H}_2\text{O}(g) \quad \Delta H^\circ_{\text{rxn}} = -4163 \text{ kJ} \]

What is the enthalpy change for the combustion of 2.50 g \text{C}_6\text{H}_{14}?  

   a. -121 kJ
   b. -1.66 \times 10^3 \text{ kJ}
   c. -1.04 \times 10^4 \text{ kJ}
   d. -1.43 \times 10^5 \text{ kJ}

8. Which of the following chemical equations corresponds to the standard molar enthalpy of formation of N\(_2\)O?

   a. \( \text{NO}(g) + 1/2 \text{N}_2(g) \rightarrow \text{N}_2\text{O}(g) \)
   b. \( \text{N}_2(g) + 1/2 \text{O}_2(g) \rightarrow \text{N}_2\text{O}(g) \)
   c. \( 2\text{N}(g) + \text{O}(g) \rightarrow \text{N}_2\text{O}(g) \)
   d. \( \text{N}_2(g) + \text{O}(g) \rightarrow \text{N}_2\text{O}(g) \)

9. The heat of vaporization of benzene, \text{C}_6\text{H}_6, is 30.8 kJ/mol at its boiling point of 80.1 °C. How much heat is required to vaporize 128 g benzene at its boiling point?

   a. 4.04 kJ
   b. 18.8 kJ
   c. 19.3 kJ
   d. 50.5 kJ
Problem

10. **2002 D**

\[ \text{H}^+(\text{aq}) + \text{OH}^-(\text{aq}) \rightarrow \text{H}_2\text{O(\ell)} \]

A student is asked to determine the molar enthalpy of neutralization, \( \Delta H_{\text{neut}} \), for the reaction represented above. The student combines equal volumes of 1.0 \text{ M} \text{ HCl} and 1.0 \text{ M} \text{ NaOH} in an open polystyrene cup calorimeter. The heat released by the reaction is determined by using the equation \( q = mc\Delta T \).

Assume the following.

• Both solutions are at the same temperature before they are combined.
• The densities of all the solutions are the same as that of water.
• Any heat lost to the calorimeter or to the air is negligible.
• The specific heat capacity of the combined solutions is the same as that of water.

(a) Give appropriate units for each of the terms in the equation \( q = mc\Delta T \). (2 pts)

(b) List the measurements that must be made in order to obtain the value of \( q \). (2 pts)

(c) Explain how to calculate each of the following.

(i) The number of moles of water formed during the experiment (1 pt)

(ii) The value of the molar enthalpy of neutralization, \( \Delta H_{\text{neut}} \), for the reaction between \( \text{HCl(\text{aq})} \) and \( \text{NaOH(\text{aq})} \) (2 pts)
(d) The student repeats the experiment with the same equal volumes as before, but this time uses 2.0 M HCl and 2.0 M NaOH.
   
   (i) Indicate whether the value of $q$ increases, decreases, or stays the same when compared to the first experiment. Justify your prediction. (1 pt)

   (ii) Indicate whether the value of the molar enthalpy of neutralization, $\Delta H_{\text{neut}}$, increases, decreases, or stays the same when compared to the first experiment. Justify your prediction. (1 pt)

(e) Suppose that a significant amount of heat were lost to the air during the experiment. What effect would this have on the calculated value of the molar enthalpy of neutralization, $\Delta H_{\text{neut}}$? Justify your answer. (1 pt)

11. Hydrogen gas burns in air according to the equation below. (2011A, 4 points total)

   \[ 2 \text{H}_2(\text{g}) + \text{O}_2(\text{g}) \rightarrow 2 \text{H}_2\text{O}(\ell) \]

   a) Calculate the standard enthalpy change, $\Delta H^\circ_{\text{rxn}}$, for the reaction represented by the equation above. (The molar enthalpy of formation, $\Delta H^\circ_{\text{f}}$, for H$_2$O($\ell$) is -285.8 kJ/mol at 298 K.

   b) Calculate the amount of heat, in kJ, that is released when 10.0 g of H$_2$(g) is burned in air.
c). Given that the molar enthalpy of vaporization, $\Delta H_{vap}^0$, for H$_2$O($\ell$) is 44.0 kJ/mol at 298 K, what is the standard enthalpy change, $\Delta H_{f,xn}^0$, for the reaction 2H$_2$(g) + O$_2$(g) $\rightarrow$ 2 H$_2$O(g)?

12. 2003 B
In another experiment, liquid heptane, C$_7$H$_{16}$(ℓ), is completely combusted to produce CO$_2$(g) and H$_2$O(ℓ), as represented by the following equation.

$$C_7H_{16}(ℓ) + 11O_2(g) \rightarrow 7CO_2(g) + 8H_2O(ℓ)$$

The heat of combustion, $\Delta H_{comb}^0$, for one mole of C$_7$H$_{16}$(ℓ) is $-4.85 \times 10^3$ kJ.

a) Using the information in the table below, calculate the value of $\Delta H_f^0$ for C$_7$H$_{16}$(ℓ) in kJ mol$^{-1}$. (2 pts)

<table>
<thead>
<tr>
<th>Compound</th>
<th>$\Delta H_f^0$ (kJ mol$^{-1}$)</th>
</tr>
</thead>
<tbody>
<tr>
<td>CO$_2$(g)</td>
<td>-393.5</td>
</tr>
<tr>
<td>H$_2$O(ℓ)</td>
<td>-285.8</td>
</tr>
</tbody>
</table>

b) A 0.0108 mol sample of C$_7$H$_{16}$(ℓ) is combusted in a bomb calorimeter.
   i) Calculate the amount of heat released to the calorimeter. (1 pt)
   ii) Given that the total heat capacity of the calorimeter is 9.273 kJ °C$^{-1}$, calculate the temperature change of the calorimeter. (1 pt)
13. 1995 B
Propane, C₃H₈, is a hydrocarbon that is commonly used as fuel for cooking.
(a) Write a balanced equation for the complete combustion of propane gas, which yields CO₂(g) and H₂O(l).

(b) The heat of combustion of propane is -2,220.1 kJ/mol. Calculate the enthalpy of formation, ΔH°, of propane given that ΔH° of H₂O(l) = -285.3 kJ/mol and ΔH° of CO₂(g) = -393.5 kJ/mol.

(c) Assuming that all of the heat evolved in burning 30.0 grams of propane is transferred to 8.00 kilograms of water (specific heat = 4.18 J/g·K), calculate the increase in temperature of water.
Chapter 5 Practice Problems

Answer Section

MULTIPLE CHOICE

1. ANS: E  PTS: 1  OBJ: 6.7 Hess's Law
2. ANS: D  PTS: 1  OBJ: 6.8 Standard Enthalpies of Formation
3. ANS: A  PTS: 1
4. ANS: C  PTS: 1
5. ANS: B  PTS: 1  OBJ: 6.2 Specific Heat Capacity and Heat Transfer
6. ANS: C  PTS: 1  OBJ: 6.5 Enthalpy Changes for Chemical Reactions
7. ANS: A  PTS: 1  OBJ: 6.8 Standard Enthalpies of Formation
8. ANS: B  PTS: 1  OBJ: 6.3 Energy and Changes of State
9. ANS: D  PTS: 1

PROBLEM

10. ANS:

   \( q \) in J, \( m \) in grams, \( C \) in J/g°C, \( T \) in °C

   (b) mass or volume of each solution

   starting temperature of each reagent

   ending temperature of mixture

   (c) (i) both are 1 M acid and base and react on a 1:1 basis

   volume \( \times x \) = mol of H⁺

   \( \text{H}^+ + \text{OH}^- \rightarrow \text{H}_2\text{O} \)

   (ii)

   (d) (i) increases. Twice as much water is produced so it is twice the energy released in the same volume of solution

   (ii) same. = same result

   (e) smaller. heat lost to the air gives a smaller amount of temperature change in the solution, which leads to a smaller measured heat release

   PTS: 1

11. ANS:

   \[ \Delta H_{298}^\circ = [2(-285.8)] - [2(0) + 1(0)] = -571.6 \text{ kJ mol}^{-1} \]

   (1 pt)

   \[ q = 10 \text{ g H}_2 \times \frac{1 \text{ mol H}_2}{2.016 \text{ g H}_2} \times \frac{285.8 \text{ kJ}}{1 \text{ mol H}_2} = 1.42 \times 10^3 \text{ kJ} \]

   (1 pt for setup, 1 pt for answer)
c) 1 pt for answer

12. ANS:
   a) -191 kJ/mol
   b) 52.4 kJ released
   c) +5.65 oC

PTS: 1

13. ANS:
   (a) C_3H_8 + 5 O_2 \rightarrow 3 CO_2 + 4 H_2O
   (b) 10.0 g C_3H_8 \times 1 \text{ mol C}_3\text{H}_8/44.0 \text{ g} \times 5 \text{ mol O}_2/1 \text{ mol C}_3\text{H}_8 = 1.14 \text{ mol O}_2

\[
V_o = \frac{nRT}{P} = \frac{(1.14 \text{ mol })(0.0821 \frac{L\text{ atm}}{\text{ mol K}})(303 \text{ K})}{1.00 \text{ atm}}
= 28.3 \text{ L O}_2; f(28.3 \text{ L},21.0\%) = 135 \text{ L of air}
\]

(c)
\[
\Delta H_{\text{comb}}^\circ = [\Delta H_{f(CO_2)}^\circ + \Delta H_{f(H_2O)}^\circ] - [\Delta H_{f(C_3H_8)}^\circ + \Delta H_{f(O_2)}^\circ]
\]

-2220.1 = [3(-393.5) + 4(-285.3)] - [X+ 0]

\[X = \Delta H_{\text{comb}}^\circ = -101.6 \text{ kJ/mol}\]

(d) \[q = 30.0 \text{ g C}_3\text{H}_8 \times 1 \text{ mol/44.0 g} \times 2220.1 \text{ kJ/1 mol} = 1514 \text{ kJ}\]

\[
q = (m)(C_p)(\Delta T)
= (8.00 \text{ kg})(4.184 \text{ J/gK})(\Delta T)
\Delta T = 45.2^\circ
\]

PTS: 1