CHAPTER 5 – THERMOCHEMISTRY

Energy Changes

1. The dimensions of the SI unit of energy, the Joule (J), are
   A. K
   B. kg m s
   C. kg m^2 s^-2
   D. kg m^-1 s^-2
   E. kg m^2 s^-1

2. Natural gas, or methane, is an important fuel. Combustion of one mole of methane releases 802.3 kilojoules of energy. How much energy does that represent in kilocalories?
   A. 3.36×10^3 kcal
   B. 3.357 kcal
   C. 191.8 kcal
   D. 0.192 kcal
   E. 1.918×10^5 kcal

3. What is the change in internal energy, \( \Delta E \), (in kJ) of a system that absorbs 100 kJ of heat and does 200 kJ of work on its surroundings?
   A. +100 kJ
   B. -100 kJ
   C. +300 kJ
   D. -300 kJ
   E. none of the above

4. Which ONE of the following statements is NOT true?
   A. The change in enthalpy for exothermic chemical reactions is negative.
   B. In an exothermic reaction, the reactants are lower in enthalpy than the products.
   C. An endothermic reaction is one in which enthalpy is absorbed by the system from the surroundings.
   D. If \( \Delta H^\circ \) is positive in the forward direction, it will be negative in the reverse direction.
   E. If the coefficients in a balanced reaction are multiplied by 2, the enthalpy change for the reaction is multiplied by 2.

5. Which one of the following is NOT an endothermic process?
   A. ice melting
   B. boiling soup
   C. water evaporating
   D. condensation of water vapor
   E. dry ice subliming (evaporating without melting)

6. The reaction shown below is ________ and therefore heat is ________ by the reaction.
   \[ 4\text{Al}(s) + 3\text{O}_2(g) \rightarrow 2\text{Al}_2\text{O}_3(s); \Delta H^\circ = -3351 \text{ kJ} \]
   A. endothermic, released
   B. exothermic, absorbed
   C. endothermic, absorbed
   D. exothermic, released
   E. none of the above

Thermochemical Equations

7. When aluminum oxide, \( \text{Al}_2\text{O}_3 \), is heated to high temperatures, it decomposes to produce aluminum metal by the following thermochemical equation:
   \[ 2\text{Al}_2\text{O}_3(s) \rightarrow 4\text{Al}(s) + 3\text{O}_2(g); \Delta H^\circ = +3352 \text{ kJ} \]
   In order to produce 75.0 g of aluminum, how much heat energy will be required?
   A. 9320 kJ
   B. 2330 kJ
   C. 1210 kJ
   D. 37300 kJ
   E. none of the above

8. In the thermite reaction, powdered aluminum reacts with iron(III) oxide to produce iron metal and aluminum oxide:
   \[ 2\text{Al}(s) + \text{Fe}_2\text{O}_3(s) \rightarrow 2\text{Fe}(s) + \text{Al}_2\text{O}_3(s); \Delta H^\circ = -852 \text{ kJ} \]
   When this reaction is carried out, 1250. kJ of heat energy are released. How many grams of iron are also formed?
   A. 82.0 g
   B. 2.97×10^4 g
   C. 164 g
   D. 328 g
   E. 9531 g

9. What is the enthalpy change (\( \Delta H^\circ \)) for the reaction
   \[ 4\text{NaCl}(s) \rightarrow 4\text{Na}(s) + 2\text{Cl}_2(g), \text{if the reaction} \]
   \[ 2\text{Na}(s) + \text{Cl}_2(g) \rightarrow 2\text{NaCl}(s) \text{ has } \Delta H^\circ = -821.8 \text{ kJ} \]
   A. +1644 kJ
   B. +410.9 kJ
   C. -1644 kJ
   D. -410.9 kJ
   E. -205.5 kJ
10. What is the maximum amount of heat that could be generated from the following reaction, starting from 10.0 g of Al and 45.0 g of Fe$_2$O$_3$? (MM Al = 26.98 g/mol, MM Fe$_2$O$_3$ = 159.69 g/mol)

\[
2\text{Al(s)} + \text{Fe}_2\text{O}_3(s) \rightarrow 2\text{Fe(s)} + \text{Al}_2\text{O}_3(s); \Delta H^\circ = -852 \text{ kJ}
\]

A. 158 kJ  
B. 240 kJ  
C. 398 kJ  
D. 316 kJ  
E. none of the above

*Hint: This is a limiting-reactant calculation.*

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### Specific Heat Capacity and Calorimetry

11. What is the specific heat capacity of a sample of a metal weighing 100.0 g that absorbs 10.0 kJ of heat energy when the temperature changes from 25.00°C to 45.00°C?

\[
Q = mc\Delta T
\]

A. 0.00500 J g$^{-1}$ °C$^{-1}$  
B. 5.00 J g$^{-1}$ °C$^{-1}$  
C. 0.500 J g$^{-1}$ °C$^{-1}$  
D. 200.0 J g$^{-1}$ °C$^{-1}$  
E. 20.0 J g$^{-1}$ °C$^{-1}$

12. If 10.0 kJ of heat energy is added to 45.0 g of water initially at 25.0°C, what will be the final temperature of the water? The specific heat of water is 4.18 J g$^{-1}$ °C$^{-1}$.

A. 95.2°C  
B. 45.2°C  
C. 53.2°C  
D. 78.2°C  
E. 62.2°C

13. Mithril is a tough, lightweight metal mined by the dwarves in the mines of Moria. A 25.00 g sample of mithril is heated in a test tube to 100.00°C in boiling water and carefully added to a coffee-cup calorimeter containing 50.00 g of water. The water temperature increased from 25.50°C to 30.50°C. What is the specific heat capacity of mithril? (The specific heat capacity of water is 4.18 J g$^{-1}$ °C$^{-1}$. We will ignore the energy absorbed by the calorimeter.)

\[
Q = mc\Delta T
\]

A. 0.325 J g$^{-1}$ °C$^{-1}$  
B. 0.225 J g$^{-1}$ °C$^{-1}$  
C. 0.876 J g$^{-1}$ °C$^{-1}$  
D. 0.601 J g$^{-1}$ °C$^{-1}$  
E. 0.476 J g$^{-1}$ °C$^{-1}$

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### Hess’s Law; Heats of Reaction

14. Which ONE of the following thermochemical equations has a value of $\Delta H^\circ$ that corresponds to the enthalpy of formation, $\Delta H_f^\circ$?

- A. 6C(s) + 6H(g) → C$_6$H$_6$(l)
- B. $\frac{1}{2}$N$_2$(g) + O$_2$(g) → NO$_2$(g)
- C. N$_2$(g) + 3H$_2$(g) → 2NH$_3$(g)
- D. H$_2$O(l) + $\frac{1}{2}$O$_2$(g) → H$_2$O$_2$(l)
- E. 2H(g) + O(g) → H$_2$O(l)

*Use Hess’s law to derive the enthalpy of the following reaction:*

\[
\text{N}_2\text{H}_4(l) + 2\text{H}_2\text{O}_2(l) \rightarrow \text{N}_2(g) + 4\text{H}_2\text{O}(l)
\]

15. Use Hess’s law to derive the enthalpy of the following reaction:

\[
\text{N}_2\text{H}_4(l) + \text{O}_2(g) \rightarrow \text{N}_2(g) + 2\text{H}_2\text{O}(l)
\]

Use the following thermochemical equations:

\[
\begin{align*}
\text{H}_2(g) + \frac{1}{2}\text{O}_2(g) &\rightarrow \text{H}_2\text{O}(l) & \Delta H &= -285.8 \text{ kJ} \\
\text{H}_2(g) + \text{O}_2(g) &\rightarrow \text{H}_2\text{O}_2(l) & \Delta H &= -187.8 \text{ kJ}
\end{align*}
\]

A. -1070.6 kJ  
B. -123.4 kJ  
C. -1364 kJ  
D. -793.0 kJ  
E. -489.8 kJ

16. Calculate the energy change for the following reaction, using the enthalpies of formation provided.

\[
\text{SO}_2\text{Cl}_2(l) + 2\text{H}_2\text{O}(l) \rightarrow 2\text{HCl}(g) + \text{H}_2\text{SO}_4(l)
\]

<table>
<thead>
<tr>
<th>Substance</th>
<th>$\Delta H_f^\circ$ (kJ/mol)</th>
</tr>
</thead>
<tbody>
<tr>
<td>SO$_2$Cl$_2$(l)</td>
<td>-394.1</td>
</tr>
<tr>
<td>H$_2$O(l)</td>
<td>-285.8</td>
</tr>
<tr>
<td>H$_2$O(g)</td>
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</tr>
<tr>
<td>HCl(g)</td>
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</tr>
<tr>
<td>HCl(aq)</td>
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<tr>
<td>H$_2$SO$_4$(l)</td>
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</tr>
<tr>
<td>H$_2$SO$_4$(aq)</td>
<td>-909.3</td>
</tr>
</tbody>
</table>

A. -105.2 kJ  
B. -32.9 kJ  
C. -1176.1 kJ  
D. +613.4 kJ  
E. -1586.2 kJ
17. Acetylene burns in air according to the following equation:

\[
2\text{C}_2\text{H}_2(\text{g}) + 5\text{O}_2(\text{g}) \rightarrow 4\text{CO}_2(\text{g}) + 2\text{H}_2\text{O}(\text{g});
\]

\[
\Delta H^\circ = -2511.6 \text{ kJ}
\]

Given that \(\Delta H_f^\circ\) of \(\text{O}_2(\text{g})\) is 0 kJ, \(\Delta H_f^\circ\) of \(\text{CO}_2(\text{g})\) is -393.5 kJ, and \(\Delta H_f^\circ\) of \(\text{H}_2\text{O}(\text{g})\) is -241.8 kJ, what is \(\Delta H_f^\circ\) of \(\text{C}_2\text{H}_2(\text{g})\)?

A. 454 kJ  
B. 227 kJ  
C. -454 kJ  
D. -227 kJ  
E. none of the above

18. Which of the following statements are true?

I. \(q\) (heat) is a state function because \(\Delta H\) is a state function and \(q = \Delta H\).

II. When 50.0 g of aluminum at 20.0°C is placed in 50.0 mL of water at 30.0°C, the \(\text{H}_2\text{O}\) will undergo a smaller temperature change than the aluminum. (The density of \(\text{H}_2\text{O}\) = 1.0 g/mL, the specific heat capacity of \(\text{H}_2\text{O}\) = 4.18 J/g°C, and the specific heat capacity of aluminum = 0.89 J/g°C)

III. When a gas is compressed, the work is negative since the surroundings are doing work on the system and energy flows out of the system.

IV. For the reaction (at constant pressure) \(2\text{N}_2(\text{g}) + 5\text{O}_2(\text{g}) \rightarrow 2\text{N}_2\text{O}_5(\text{g})\), the change in enthalpy is the same whether the reaction takes place in one step or in a series of steps.

A. I, II, IV  
B. II, III  
C. II, III, IV  
D. II, IV  
E. All of the above statements are true.