PART I: MULTIPLE CHOICE

1. An endothermic reaction causes the surroundings to
   a. warm up.  
   b. become acidic.  
   c. condense.  
   d. [decrease in temperature]  
   e. [release CO\textsubscript{2}]

2. Which of the following is an example of potential energy?
   a. [Hitting a baseball]  
   b. [Running around bases]  
   c. [Pitching a baseball]  
   d. [A bat lying on the ground]  
   e. [Sliding into home plate]

3. The First Law of Thermodynamics states that:
   a. [Molecules move faster as temperature increases.]  
   b. [The total energy of the universe is constant]  
   c. [Energy transfers from hotter objects to cooler objects.]  
   d. [Samples with different temperatures that come in contact with one another will reach thermal equilibrium.]  
   e. All of the above.

4. Which property can be used to distinguish one substance from another substance?
   a. Temperature  
   b. [Enthalpy]  
   c. [Internal energy]  
   d. [Specific heat capacity]  
   e. Kinetic energy

5. Which term refers to a quantity of heat transferred at constant pressure?
   a. Entropy  
   b. [Enthalpy]  
   c. Work  
   d. Specific heat capacity  
   e. Expansion

6. If a 10.0 g sample of each substance below has 250 J applied to it, which substance will have the greatest increase in temperature?
   a. Iron (specific heat = 0.46 J/g\textdegree C)  
   b. Water (specific heat = 4.184 J/g\textdegree C)  
   c. Copper (specific heat = 0.39 J/g\textdegree C)  
   d. Aluminum (specific heat = 0.92 J/g\textdegree C)  
   e. [Lead (specific heat = 0.13 J/g\textdegree C)]

7. The temperature of a 15.5 g sample of a metal increases by 35.0 \degree C when 125 J of energy is applied to it. What is the identity of the metal?
   a. Silver (specific heat = 0.23 J/g\textdegree C)  
   b. Copper (specific heat = 0.39 J/g\textdegree C)  
   c. Iron (specific heat = 0.46 J/g\textdegree C)  
   d. Lead (specific heat = 0.13 J/g\textdegree C)  
   e. Aluminum (specific heat = 0.92 J/g\textdegree C)

8. Copper metal has a specific heat of 0.385 J/g\textdegree C. Calculate the amount of heat required to raise the temperature of 22.8 g of Cu from 20.0\degree C to 875\degree C.
   a. \(1.97 \times 10^5\) J  
   b. \(1.0 \times 10^5\) J  
   c. 329 J  
   d. [7.51 kJ]  
   e. 10.5 kJ

9. A glass containing 200. g of H\textsubscript{2}O at 20\degree C was placed in a refrigerator. The water loses 11.7 kJ as it cools to a constant temperature. What is its new temperature? The specific heat of water is 4.184 J/g\textdegree C.
   a. 0.013\degree C  
   b. 4\degree C  
   c. [6\degree C]  
   d. 14\degree C  
   e. 34\degree C
10. Suppose a 50.0 g block of silver (specific heat = 0.2350 J/g·°C) at 100°C is placed in contact with a 50.0 g block of iron (specific heat = 0.4494 J/g·°C) at 0°C, and the two blocks are insulated from the rest of the universe. The final temperature of the two blocks.
   a. will be higher than 50°C.
   b. will be lower than 50°C.
   c. will be exactly 50°C.
   d. is unrelated to the composition of the blocks.
   e. cannot be predicted.

11. A 0.1326 g sample of magnesium was burned in an oxygen bomb calorimeter. The total heat capacity of the calorimeter plus water was 5,760 J/°C. If the temperature increase of the calorimeter with water was 0.570°C, calculate the enthalpy of combustion of magnesium.

\[
\text{Mg(s) + } \frac{1}{2}\text{O}_2(g) \rightarrow \text{MgO(s)}
\]

a. -3280 kJ/mol  
   b. -24.8 kJ/mol 
   c. 435 kJ/mol 
   d. 106 kJ/mol  
   e. -602 kJ/mol  

12. To which one of these reactions occurring at 25°C does the symbol \(\Delta H^\circ_F\) [\(\text{H}_2\text{SO}_4(l)\)] refer?

a. \(2\text{H}(g) + \text{S}(g) + 4\text{O}(g) \rightarrow \text{H}_2\text{SO}_4(l)\)
   b. \(\text{H}_2(g) + \text{S}(g) + 2\text{O}_2(g) \rightarrow \text{H}_2\text{SO}_4(l)\)
   c. \(\text{H}_2\text{SO}_4(l) \rightarrow \text{H}_2(g) + \text{S}(s) + 2\text{O}_2(g)\)
   d. \(\text{H}_2\text{SO}_4(l) \rightarrow 2\text{H}(g) + \text{S}(s) + 4\text{O}(g)\)
   e. \(\text{H}_2(g) + \text{S}(s) + 2\text{O}_2(g) \rightarrow \text{H}_2\text{SO}_4(l)\)

13. Octane (\(\text{C}_8\text{H}_{18}\)) undergoes combustion according to the following thermochemical equation:

\[
2\text{C}_8\text{H}_{18}(l) + 25\text{O}_2(g) \rightarrow 16\text{CO}_2(g) + 18\text{H}_2\text{O}(l) \quad \Delta H^\circ_{\text{rxn}} = -11,020 \text{ kJ/mol}
\]

Given that \(\Delta H^\circ_F[\text{CO}_2(g)] = -393.5 \text{ kJ/mol}\) and \(\Delta H^\circ_F[\text{H}_2\text{O}(l)] = -285.8 \text{ kJ/mol}\), calculate the standard enthalpy of formation of octane.

a. \[210 \text{ kJ/mol}\]  
   b. -1,123.0 kJ/mol  
   c. 22,040 kJ/mol  
   d. -420 kJ/mol  
   e. 420 kJ/mol  

14. Given 2\(\text{Al}(s) + (3/2)\text{O}_2(g) \rightarrow \text{Al}_2\text{O}_3(s)\), \(\Delta H^\circ = -1,670 \text{ kJ/mol}\) for \(\text{Al}_2\text{O}_3\) (s).

Determine \(\Delta H^\circ\) for the reaction \(2\text{Al}_2\text{O}_3(s) \rightarrow 4\text{Al}(s) + 3\text{O}_2(g)\)

a. \[3,340 \text{ kJ/mol}\]  
   b. 1,670 kJ/mol  
   c. -3,340 kJ/mol  
   d. -1,670 kJ/mol  
   e. -835 kJ/mol  

15. Given the thermochemical equation \(2\text{SO}_2 + \text{O}_2 \rightarrow 2\text{SO}_3\), \(\Delta H^\circ_{\text{rxn}} = -198 \text{ kJ/mol}\), what is the standard enthalpy change for the decomposition of one mole of \(\text{SO}_3\)?

a. 198 kJ/mol  
   b. -198 kJ/mol  
   c. 99 kJ/mol  
   d. 396 kJ/mol  
   e. -396 kJ/mol  

16. For the reaction \(\text{C(graphite)} + \text{O}_2(g) \rightarrow \text{CO}_2(g)\), \(\Delta H^\circ = -393 \text{ kJ/mol}\). How many grams of \(\text{C(graphite)}\) must be burned to release 275 kJ of heat?

a. 22.3 g  
   b. 0.70 g  
   c. 12.0 g  
   d. 17.1 g  
   e. 8.40 g
17. Find the heat absorbed from the surroundings when 15 g of O\textsubscript{2} reacts according to the equation O + O\textsubscript{2} → O\textsubscript{3}, \( \Delta H\textsubscript{rxn} = 103 \) kJ/mol.
   a. 4.6 \times 10^{-3} \text{ kJ}   
   b. 48 \text{ kJ}   
   c. 96 \text{ kJ} 
   d. 32 \text{ kJ} 
   e. 110 \text{ kJ} 

18. At 25°C, the standard enthalpy of formation of KCl(s) is -435.87 kJ/mol. When one mole of KCl(s) is formed by reacting potassium vapor and chlorine gas at 25°C, the standard enthalpy of reaction is -525.86 kJ/mol. Find \( \Delta H^\circ \) for the sublimation of potassium, K(s) → K(g), at 25°C.
   a. -345.88 kJ/mol 
   b. 45.00 kJ/mol 
   c. 345.88 kJ/mol 
   d. 89.99 kJ/mol 
   e. -525.86 kJ/mol 

19. 10.1 g CaO is dropped into a styrofoam coffee cup containing 157 g H\textsubscript{2}O at 18.0°C. If the following reaction occurs, then what temperature will the water reach, assuming that the cup is a perfect insulator and that the cup absorbs only a negligible amount of heat? [specific heat of water = 4.18 J/g·°C] 

\[
\text{CaO(s) + H}_2\text{O(l)} \rightarrow \text{Ca(OH)}_2(s) \quad \Delta H = -64.8 \text{ kJ/mol}
\]
   a. 18.02°C 
   b. 35.8°C 
   c. 311°C 
   d. 42.2°C 
   e. 117°C 

20. A gas is compressed in a cylinder from a volume of 20 L to 2.0 L by a constant pressure of 10.0 atm. Calculate the amount of work done on the system.
   a. 1.01 \times 10^4 \text{ J} 
   b. -180 J 
   c. 1.81 \times 10^4 \text{ J} 
   d. -1.81 \times 10^4 \text{ J} 
   e. 180 J 

21. Which of the following processes always results in an increase in the energy of a system?
   a. The system loses heat and does work on the surroundings. 
   b. The system gains heat and does work on the surroundings. 
   c. The system loses heat and has work done on it by the surroundings. 
   d. The system gains heat and has work done on it by the surroundings. 
   e. None of these is always true. 

22. For which of these reactions will the difference between \( \Delta H^\circ \) and \( \Delta E^\circ \) be the smallest?
   a. \text{N}_2(g) + 3\text{H}_2(g) \rightarrow 2\text{NH}_3(g) 
   b. 4\text{PH}_3(g) \rightarrow \text{P}_4(g) + 6\text{H}_2(g) 
   c. \text{H}_2(g) + \text{Cl}_2(g) \rightarrow 2\text{HCl}(g) 
   d. \text{CO}_2(g) + 2\text{H}_2\text{O}(l) \rightarrow \text{CH}_4(g) + 2\text{O}_2(g) 
   e. \text{P}_4(s) + 10\text{Cl}_2(g) \rightarrow 4\text{PCl}_5(s) 

**PART II: CONCEPTS**

23. For each of the following, determine the value of \( \Delta H_2 \) in terms of \( \Delta H_1 \).

\[
\text{A} + \text{B} \rightarrow 2\text{C} \quad \Delta H_1 
\]

a. \( 2\text{C} \rightarrow \text{A} + \text{B} \quad \Delta H_2 = \) ?

**Answer:** The second equation is obtained by reversing the first one. Therefore \( \Delta H_2 = -\Delta H_1 \)
\[
\text{A} \rightarrow \text{B} + 2\text{C} \quad \Delta H_1
\]

b. \[\frac{1}{2} \text{B} + \text{C} \rightarrow \frac{1}{2} \text{A} \quad \Delta H_2 = ?\]

**Answer:** The second equation is obtained by reversing the first one and dividing it by 2. Therefore \(\Delta H_2 = -\frac{1}{2} \Delta H_1\)

**PART III: HESS’S LAW**

24. Calculate \(\Delta H\) for the following reaction:

\[
\text{Fe}_2\text{O}_3 (s) + 3 \text{CO (g)} \rightarrow 2 \text{Fe (s)} + 3 \text{CO}_2 (g)
\]

Use the following reactions:

1) \(2 \text{Fe (s)} + \frac{3}{2} \text{O}_2 (g) \rightarrow \text{Fe}_2\text{O}_3 (s) \quad \Delta H = -824.2 \text{kJ}\)
2) \(\text{CO (g)} + \frac{1}{2} \text{O}_2 (g) \rightarrow \text{CO}_2 (g) \quad \Delta H = -282.7 \text{kJ}\)

**Answer:** We need to reverse equation (1) since \(\text{Fe}_2\text{O}_3 (s)\) is on the reactant side in the equation in question. Equation (2) needs to be multiplied by 3 since the studied equation involves 3 moles of \(\text{CO (g)}\). As a result:

1) \(\text{Fe}_2\text{O}_3 (s) \rightarrow 2 \text{Fe (s)} + \frac{3}{2} \text{O}_2 (g) \quad \Delta H = +824.2 \text{kJ}\)
2) \(3 \text{CO (g)} + \frac{3}{2} \text{O}_2 (g) \rightarrow 3 \text{CO}_2 (g) \quad \Delta H = -848.1 \text{kJ}\)

Add equations (1) and (2):

\[
\text{Fe}_2\text{O}_3 (s) + 3 \text{CO (g)} + \frac{3}{2} \text{O}_2 (g) \rightarrow 2 \text{Fe (s)} + \frac{3}{2} \text{O}_2 (g) + 3 \text{CO}_2 (g)
\]

\(\Delta H = +824.2 \text{kJ} + (-848.1 \text{kJ}) = -23.9 \text{kJ}\)

**PART IV: STANDARD MOLAR ENTHALPIES OF FORMATION**

25. Write an equation for the formation of each of the following compounds from their constituent elements, in their standard states.

a. \(\text{NO}_2 (g)\)
   \[\frac{1}{2} \text{N}_2 (g) + \text{O}_2 (g) \rightarrow \text{NO}_2 (g)\]

b. \(\text{C}_2\text{H}_4 (g)\)
   \[2 \text{C (graphite)} + 2 \text{H}_2 (g) \rightarrow \text{C}_2\text{H}_4 (g)\]

c. \(\text{MgCO}_3 (s)\)
   \[\text{Mg (s)} + \text{C (graphite)} + \frac{3}{2} \text{O}_2 (g) \rightarrow \text{MgCO}_3 (s)\]

d. \(\text{CH}_3\text{OH (l)}\)
   \[\text{C (graphite)} + 2 \text{H}_2 (g) + \frac{1}{2} \text{O}_2 (g) \rightarrow \text{CH}_3\text{OH (l)}\]

26. Use data on \(\Delta H_f^\circ\) (Table 6.2 and Appendix 4) to calculate \(\Delta H\) for each of the following reactions.

a. \(2 \text{H}_2\text{S (g)} + 3 \text{O}_2 (g) \rightarrow 2 \text{H}_2\text{O (l)} + 2 \text{SO}_2 (g)\)

**Answer:** We know that, in general, \(\Delta H\) for any reaction can be determined if we know the \(\Delta H_f^\circ\) values of all reactants and products, using the equation:

\[
\Delta H = \Sigma n \times \Delta H_f^\circ (\text{products}) - \Sigma m \times \Delta H_f^\circ (\text{reactants})
\]
From Table 6.2: \( \Delta H_f^o (H_2O(l)) = -286 \text{ kJ/mol} \)

From Appendix 4: \( \Delta H_f^o (H_2S(g)) = -21 \text{ kJ/mol} \)
\( \Delta H_f^o (SO_2(g)) = -297 \text{ kJ/mol} \)

We also know that for elements, in their standard states, \( \Delta H_f^o = 0 \text{ kJ/mol} \). Therefore \( \Delta H_f^o (O_2(g)) = 0 \text{ kJ/mol} \)

Using the above equation:

\[ \Delta H = 2 \times (-286) + 2 \times (-297) - 2 \times (-21) = -1124 \text{ kJ} \]

\[ \Delta H = -1124 \text{ kJ} \]

b. \( \text{N}_2\text{O}_4(g) \quad + \quad 4 \text{H}_2(g) \quad \rightarrow \quad \text{N}_2(g) \quad + \quad 4 \text{H}_2\text{O}(g) \)

Answer: We use the same general equation:

\[ \Delta H = \Sigma n \times \Delta H_f^o (\text{products}) - \Sigma m \times \Delta H_f^o (\text{reactants}) \]

From Table 6.2: \( \Delta H_f^o (H_2O(g)) = -242 \text{ kJ/mol} \)

From Appendix 4: \( \Delta H_f^o (\text{N}_2\text{O}_4(g)) = +10 \text{ kJ/mol} \)

For elements, in their standard states, \( \Delta H_f^o = 0 \text{ kJ/mol} \). Therefore \( \Delta H_f^o (\text{H}_2 (g)) = 0 \text{ kJ/mol} \)
\( \Delta H_f^o (\text{N}_2 (g)) = 0 \text{ kJ/mol} \)

Using the above equation:

\[ \Delta H = 4 \times (-242) - 1 \times 10 = -978 \text{ kJ} \]

\[ \Delta H = -978 \text{ kJ} \]