1. Multiple Choice (problems with asterisks must show work)

*1. Given chemical equations for these reactions

\[
\begin{align*}
S(s) + O_2(g) &\rightarrow SO_2(g) & \Delta H^\circ = -296.8 \text{ kJ/mol}^{-1} \\
H_2(g) + \frac{1}{2} O_2(g) &\rightarrow H_2O(l) & \Delta H^\circ = -285.8 \text{ kJ/mol}^{-1} \\
H_2(g) + S(s) &\rightarrow H_2S(g) & \Delta H^\circ = -20.6 \text{ kJ/mol}^{-1}
\end{align*}
\]

What is the value of \( \Delta H \) for the reaction below?

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

(A) \(-603.2 \text{ kJ/mol}^{-1}\)  
(B) \(-562.0 \text{ kJ/mol}^{-1}\)  
(C) \(-1206.4 \text{ kJ/mol}^{-1}\)  
(\(\bigcirc\)) \(-1124.0 \text{ kJ/mol}^{-1}\)

*2. Calculate the energy released by the reaction \(4 \text{Fe}(s) + 3 \text{O}_2(g) \rightarrow 2 \text{Fe}_2\text{O}_3(s)\) when a 55.8 g sample of iron reacts completely with 1.00 mole of oxygen. The enthalpy of formation (\(\Delta H^\circ\)) of \(\text{Fe}_2\text{O}_3(s)\) is \(-826 \text{ kJ/mol}^{-1}\).

\[
\begin{align*}
\text{Fe} &\rightarrow [\text{Fe}^{++} + 2\text{e}^-] \\
\text{Fe}(s) &\rightarrow 4\text{mol Fe}^{++} \\
\text{O}_2 &\rightarrow 2\text{mol O}^{2-} \\
\text{Fe}_2\text{O}_3 &\rightarrow 1\text{mol Fe}_2\text{O}_3 \\
\end{align*}
\]

\[
\frac{1.00 \text{ mol } \text{O}_2 \times 2 \text{ mol } \text{FeO}_3}{1 \text{ mol } \text{Fe}_2\text{O}_3} = 2 \text{ mol } \text{FeO}_3 \\
\frac{2 \text{ mol } \text{FeO}_3 \times 826 \text{ kJ}}{1 \text{ mol } \text{Fe}_2\text{O}_3} = 1652 \text{ kJ}
\]

What is the change in energy for this reaction?

(A) 206 kJ  
(B) 413 kJ  
(C) 826 kJ  
(D) 1650 KJ

3. The specific heat capacities of three metals are given below:

<table>
<thead>
<tr>
<th>Metal</th>
<th>Specific heat, J·g(^{-1}·\text{C}^{-1})</th>
</tr>
</thead>
<tbody>
<tr>
<td>Fe</td>
<td>0.470</td>
</tr>
<tr>
<td>Pb</td>
<td>0.130</td>
</tr>
<tr>
<td>Zn</td>
<td>0.388</td>
</tr>
</tbody>
</table>

If 1.00 g of each metal is heated to 100 °C and added to 10.0 g of H\(_2\)O at 25.0 °C, what is the order of the temperatures of the final mixtures from the lowest to the highest?

(A) Fe < Zn < Pb  
(B) Pb < Zn < Fe  
(C) Zn < Pb < Fe  
(D) Zn < Fe < Pb

4. The enthalpy change, \(\Delta H_{rxn}\), of a process is defined as:

A. The maximum amount of useful work that can be done in a system.
B. The increase or decrease in temperature in a system.
C. The quantity of heat transferred in or out of a system as it undergoes a change at constant pressure.
D. The change in molecular disorder in a system.
E. None of these are correct.

5. For which of the following substances does \(\Delta H^\circ = 0\)? Or asked another way, which of these substances is the lowest energy form of an element?

A. CO\(_2\)(g)
B. H\(_2\)O(g)
C. Na(s)
D. Br\(_2\)(g)
E. C(diamond)

6. Which one of the following techniques cannot be used to calculate \(\Delta H_{rxn}\)?

A. Calorimetry  
B. Using melting points of reactants and products  
C. Hess's Law  
D. Using Heats of Formation of reactants and products
7. Hydrazine is an inorganic compound with the formula N₂H₄. It has many uses including a propellant and rocket fuel. Hydrazine is synthesized from ammonia and hydrogen peroxide according to the equation below.

\[ 98 \text{kJ} + 2 \text{NH}_3 + \text{H}_2\text{O}_2 \rightarrow \text{N}_2\text{H}_4 + 2 \text{H}_2\text{O} \]

Which of the following statements is true about the reaction above?

i. The ΔH for this process is negative.  
ii. The reactants are higher in internal energy and less stable than the products.  
iii. The ΔH for this process is positive.  
iv. The products are higher in internal energy and less stable than the reactants.

A. i and ii  
B. ii and iv  
C. ii and iii  
D. iii and iv  
E. iii only

8. The amount of heat energy in Joules required to raise the temperature of one gram of any substance 1°C is called the:

A. specific heat capacity  
B. calorie  
C. enthalpy  
D. change in enthalpy  
E. imp

9. A function whose value depends only on its initial and final conditions is called a state function. Two examples of state functions in chemistry are:

A. ΔU and ΔH  
B. work and heat  
C. ΔH and work  
D. ΔH and heat  
E. CA and MD

10. Two aqueous solutions are both at room temperature and are then mixed in a coffee cup calorimeter. The reaction causes the temperature of the resulting solution to fall below room temperature. Which of the following statements is TRUE?

A) The products have a lower potential energy than the reactants.  
B) This type of experiment will provide data to calculate ΔZ_mol.  
C) The reaction is endothermic.  
D) Energy is leaving the system during reaction.  
E) None of the above statements are true.

**II. Short Answer**

1. Use standard enthalpies of formation from the equation sheets or the back of your book to calculate ΔH^\circ_rxn for each reaction. Then draw a Reaction Energy diagram for each reaction using "Reaction Progress on the x-axis and Potential Energy on the y-axis. Label ΔH^\circ_rxn, reactants and products on each diagram.

A. \[ 2 \text{H}_2\text{S}(g) + 3 \text{O}_2(g) \rightarrow 2 \text{H}_2\text{O}(g) + 2 \text{SO}_2(g) \]

\[ \Delta H^\circ_rxn = -20.6 \quad \text{kJ/mol} \]

B. \[ \text{SO}_2(g) + \frac{1}{2} \text{O}_2(g) \rightarrow \text{SO}_3(g) \]

C. \[ \text{N}_2(g) + 3 \text{H}_2(g) \rightarrow 2 \text{NH}_3(g) + 4 \text{H}_2(g) \]

\[ \Delta H^\circ_rxn = \begin{align*} 2 \text{(-241.8)} + 2 \text{(-296.8)} - [2 \text{(-20.6)} + 3 \text{(0)}] &= -1036 \text{ kJ/mol} \end{align*} \]
2. Heat exchange between two materials: A pre-1982 pure copper penny with a mass of 3.0145 g initially at 100.0°C is submerged into 5.05 g of water at 16.8°C in a coffee thimble calorimeter. What is the final temperature of both substances at thermal equilibrium—when all temperature changes are complete and the final temperature of the pure copper and water are equal?

\[ q_{\text{penny}} = -q_{\text{water}} \]

\[(3.0145\text{g})(0.385\text{J/g°C})(T_f - 100.0°C) = -(5.05\text{g})(4.184\text{J/g°C})(T_f - 16.8°C) \]

\[1.16T_f - 116 = -21.1T_f + 355\]

\[22.26T_f = 471\]

\[T_f = 21.2°C\]

3. Heat exchange between water and a reaction: Dry ice is solid carbon dioxide. Instead of melting, solid carbon dioxide sublimes according to the equation,

\[ \text{CO}_2(s) \rightarrow \text{CO}_2(g) \]

\[ \Delta H_{\text{rxn}}^{\circ} = -393.5 \text{ J} - (-427.4) = +33.9 \text{ kJ/mol} \]

Last night when I was out clubbing, I went back stage to see how their fog machine worked. It turns out that the entire fog machine was comprised of 10.0 L of water at 85.0°C, some dry ice, a fan and some tubing. When dry ice is put into the hot water, the dry ice sublimes to CO2(g). The CO2(g) and some H2O(g) form fog that then gets blown by the fan through the tubing.

10.0L water = 10,000g H2O

Assuming no heat loss to the surroundings (and that all of the heat lost by the water cooling goes to sublime the dry ice), I immediately calculated the grams of dry ice that were needed to exactly cool the water from 85.0°C to 10.0°C. I needed to recall that \( \Delta H_f \) for CO2(s) is −427.4kJ/mol (I always go out with Taro, but even the text didn't have this piece of info).

A. What is \( \Delta H_{\text{rxn}} \) for the sublimation of CO2? To calculate this, use the \( \Delta H_f \) values for the sublimation reaction.
B. How many grams of CO2(s) did I calculate?
C. How many L of CO2 gas at 1 atm and 22°C would be created?

B. \( q_{\text{CO}_2} = -q_{\text{water}} \)

\[ q_{\text{water}} = (10,000\text{g})(4.184\text{J/g°C})(85.0 - 10.0°C) \]

\[ q_{\text{CO}_2} = +3,138,000\text{J} = \Delta H_{\text{rxn}} \text{ (mol CO}_2\text{)} \]

\[ = 33,900 \text{ J/mol (mol CO}_2\text{)} \]

\[ \text{mol CO}_2 = 92.6 \text{ mol CO}_2 = 4.08 \times 10^3 g \text{ CO}_2 \]

C. \[ PV = nRT \]

\[ V = \frac{nRT}{P} = \frac{(92.6 \text{ mol})(0.08206 \frac{\text{L atm}}{\text{mol K}})(295 \text{ K})}{1 \text{ atm}} \]

\[ = 2.24 \times 10^3 \text{ L of CO}_2(g) \]
4. Heat exchange between a solution and a reaction: A 50.0 mL sample of 0.600 M NaOH is mixed with a 150.0 mL sample of 0.400 M HNO₃ in a coffee cup calorimeter. If both solutions were initially at 35.00°C and the temperature of the resulting solution was recorded as 37.00°C, determine the ΔH_rxn (in units of kJ/mol NaOH) for the neutralization reaction between aqueous NaOH and HNO₃. Assume 1) that no heat is lost to the calorimeter or the surroundings, and 2) that the density and the heat capacity of the resulting solution are the same as water.

\[
\begin{align*}
0.0500 \text{ L} & \quad 0.600 \text{ mol NaOH} \quad \text{1 L soln} = 0.0300 \text{ mol NaOH L}^{-1} \\
0.150 \text{ L} & \quad 0.400 \text{ mol HNO}_3 \quad \text{1 L soln} = 0.06 \text{ mol HNO}_3
\end{align*}
\]

\[Q_{\text{soln}} = (50.0 \text{ g} + 150.0 \text{ g})(4.18 \text{ J/g°C})(37.00 \text{ °C} - 35.00 \text{ °C}) = +1673.6 \text{ J}\]

\[Q_{\text{rxn}} = -1673.6 \text{ J} = \Delta H_{\text{rxn}}(0.0300 \text{ mol NaOH})\]

\[\Delta H_{\text{rxn}} = -5578.7 \text{ J/mmol} = -55.8 \text{ kJ/mol}\]

5. Using Hess' Law calculate ΔH_rxn for the reaction:

\[\text{C}_3\text{H}_8(\ell) \rightarrow 5 \text{ C(s)} + 6 \text{ H}_2(\ell)\]

given the following reactions and ΔH_rxn values:

\[\begin{align*}
-1(5 \text{ CO}_2(\ell) + 6 \text{ H}_2(\ell) & \rightarrow \text{C}_3\text{H}_8(\ell) + 8 \text{ O}_2(\ell)) \\
-5(\text{C(s)} + 2 \text{ O}_2(\ell) & \rightarrow \text{CO}_2(\ell)) \\
-3(2 \text{ H}_2(\ell) + \text{O}_2(\ell) & \rightarrow 2 \text{ H}_2\text{O}(\ell))
\end{align*}\]

\[\begin{align*}
\Delta H_{\text{rxn}} &= 3505.8 \text{ kJ/mol} \\
\Delta H_{\text{rxn}} &= -393.5 \text{ kJ/mol} \\
\Delta H_{\text{rxn}} &= -483.5 \text{ kJ/mol}
\end{align*}\]

\[\begin{align*}
\text{C}_3\text{H}_8(\ell) + 8 \text{ H}_2\text{O}(\ell) & \rightarrow 5 \text{ CO}_2(\ell) + 6 \text{ H}_2\text{O}(\ell) \quad -3505.8 \text{ kJ/mol} \\
5 \text{ CO}_2(\ell) & \rightarrow 5 \text{ C(s)} + 5 \text{ O}_2(\ell) \quad 1967.5 \\
6 \text{ H}_2\text{O}(\ell) & \rightarrow 6 \text{ H}_2(\ell) + 3 \text{ O}_2(\ell) \quad 1450.5
\end{align*}\]

\[\Delta H_{\text{rxn}} = -87.8 \text{ kJ/mol}\]
6. Stoichiometry involving energy: Liquid hydrogen peroxide, a component of many rocket fuel mixtures, releases oxygen gas on decomposition. A rocket contains, say, 2.00×10³ kg of liquid hydrogen peroxide.

\[ 2 \text{H}_2\text{O}_2(\ell) \rightarrow 2 \text{H}_2\text{O}(\ell) + \text{O}_2(\text{g}) \quad \Delta \text{H}_{\text{rxn}} = -196.1 \text{ kJ/mol} \]

\[ 2.00 \times 10^3 \text{ kg H}_2\text{O}_2 = 2.00 \times 10^6 \text{ g H}_2\text{O}_2 \]

A. How much energy is released if all of the hydrogen peroxide is reacted?

\[
\begin{align*}
2.00 \times 10^6 \text{ g H}_2\text{O}_2 & | 1 \text{ mol H}_2\text{O}_2 | -196.1 \text{ kJ} \\
34.02 \text{ g H}_2\text{O}_2 & | 2 \text{ mol H}_2\text{O}_2 \\
\hline
= 5.7 \times 10^6 \text{ kJ}
\end{align*}
\]

B. How many liters of oxygen gas are released if all of the hydrogen peroxide is reacted? Assume atmospheric conditions of 1 atm and 25°C.

\[
\begin{align*}
2.00 \times 10^6 \text{ g H}_2\text{O}_2 & | 1 \text{ mol H}_2\text{O}_2 | 1 \text{ mol O}_2 \\
34.02 \text{ g H}_2\text{O}_2 & | 2 \text{ mol H}_2\text{O}_2 \\
\hline
= 2.94 \times 10^4 \text{ mol O}_2
\end{align*}
\]

\[ P \cdot V = n \cdot R \cdot T \]

\[ V = \frac{n \cdot R \cdot T}{P} = \frac{(2.94 \times 10^4 \text{ mol O}_2)(0.08206 \frac{\text{L} \cdot \text{atm}}{\text{mol} \cdot \text{K}})(298 \text{ K})}{1 \text{ atm}} = 7.19 \times 10^5 \text{ L} \]

7. PV Work: How much work (in Joules) is done by a gas when it expands from a volume of 1.00 L to a volume of 19.0 L at a constant pressure of 1.50 atm?

\[ w = -P \Delta V = -P (V_f - V_i) \]

\[ = -(1.50 \text{ atm})(19.0 \text{ L} - 1.00 \text{ L}) = -270 \text{ L} \cdot \text{atm} \]

\[ 1 \text{ L} \cdot \text{atm} = 101.325 \text{ J} \]

\[ -270 \text{ L} \cdot \text{atm} \left| \frac{101.325 \text{ J}}{1 \text{ L} \cdot \text{atm}} \right| = -2.74 \times 10^3 \text{ J} \]
PV Work:
A. How much work in Joules does it take to pump a bicycle pump if the initial volume is 4 L, the final volume is 0.2 L, and you apply 20 atmospheres of pressure to compress the pump in one step? The initial pressure is 1 atm.

\[ w = -P \Delta V \]
\[ = -(20 \text{ atm})(0.2 \text{ L} - 4 \text{ L}) \]
\[ = 76 \text{ L} \cdot \text{atm} \]
\[ \frac{76 \text{ L} \cdot \text{atm}}{1 \text{ L} \cdot \text{atm}} = 7.76 \times 10^3 \text{ J} \]

B. From lecture, you remember that the amount of work is path-dependent, and being lazy as all good scientists are, you decide to see if it takes less work to compress the pump in two steps:

i. Step 1: compress from 1 atm to 10 atm. You'll need to calculate the volume at this pressure.
ii. Step 2: compress from 10 atm to 20 atm.

How much work total is needed for these two steps (add up the work from each step)?

1. \[ W_1 = -P \Delta V = -10 \text{ atm}(0.4 \text{ L} - 4 \text{ L}) \]
\[ P_1 V_1 = P_2 V_2 \]
\[ (1 \text{ atm})(4 \text{ L}) = (10 \text{ atm})(V_2) \Rightarrow V_2 = 0.4 \text{ L} \]
\[ W_1 = 36 \text{ L} \cdot \text{atm} \]

2. \[ W_2 = -P \Delta V = -20 \text{ atm}(0.2 \text{ L} - 0.4 \text{ L}) \]
\[ W_2 = 4 \text{ L} \cdot \text{atm} \]

\[ W_{\text{total}} = W_1 + W_2 = 36 + 4 \text{ L} \cdot \text{atm} = 40 \text{ L} \cdot \text{atm} = 4.05 \times 10^3 \text{ J} \]