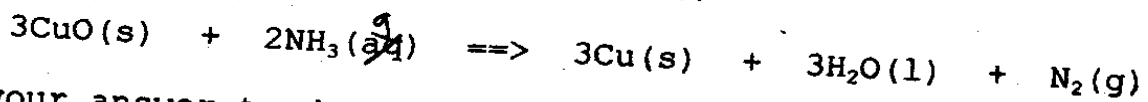


SCH OA1  
Thermodynamics Test

1. For each of the following, label with a + for an increase in potential energy or a - for a decrease in potential energy. Be careful. One-half mark will be deducted for each incorrect response.

- (10)
- 10
- a) - the combustion of methane gas  
 b) + the formation of diamond deep within the earth's crust  
 c) = formation of frost on a window through a sublimation process  
 d) + formation of benzene (l)  
 e) + a reaction in which the reactants have greater forces or attraction than the products  
 f) - heat energy is absorbed by the water jacket in a bomb calorimeter (consider the change in enthalpy of the reaction only)  
 g) + formation of an onion from all necessary raw materials  
 h) + the conversion of ethyl alcohol to dimethyl ether  
 i) - deflation of a balloon  
 f) + build up of electrostatic charge in a thunderhead

2. Use the summation of heats of formation method (i.e. not Hess Law) to calculate the heat of reaction for:



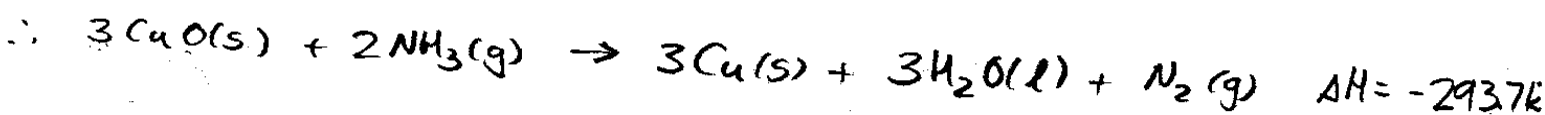
Use your answer to determine:

- a) the heat released if 500 g of Cu(s) is recovered  
 b) 1.5 L of nitrogen gas is recovered at S.T.P. (22.414 L of gas = 1 mol of gas)

$$\Delta H = [3\Delta H^\circ_{\text{Cu}(s)} + 3\Delta H^\circ_{\text{H}_2\text{O}(l)} + \Delta H^\circ_{\text{N}_2(g)}] - [3\Delta H^\circ_{\text{CuO}(s)} + 2\Delta H^\circ_{\text{NH}_3(g)}] \checkmark$$

$$\Delta H = [3(0) + 3(-285.8\text{kJ}) + (0)] - [3(-157.3\text{kJ}) + 2(-45.9)]$$

$$\Delta H = -293.7\text{kJ} \checkmark$$



$$Q = -\Delta H \checkmark$$

$$Q = 293.7\text{kJ}$$

$$500\text{g Cu} \times \frac{1\text{mol Cu}}{63.54\text{g Cu}} \times \frac{293.7\text{kJ}}{3\text{mol Cu}} = 770.4\text{kJ} \checkmark$$

$$1.5\text{L N}_2 \times \frac{1\text{mol N}_2}{22.414\text{L N}_2} \times \frac{293.7\text{kJ}}{1\text{mol N}_2} = 19.66\text{kJ} \checkmark$$

3. When 10 g of butane ( $C_4H_{10}$ ) is reacted with sufficient oxygen to allow complete combustion 30 L of water in a bomb calorimeter is warmed from 20.00 °C to 23.94 °C. Use this information plus appropriate heats of formation (i.e. values for carbon dioxide, water and oxygen) to derive the heat of formation for the compound butane. Check this answer with the heat of formation value for butane found in the table in your text to see if the information in this question is correct. Please perform your calculation in kJ. Do not use Hess' Law.

$$Q = mc\Delta T$$

$$Q = 30000 \text{ g} \times 4.184 \text{ J/g}^\circ\text{C} \times 3.94^\circ\text{C}$$

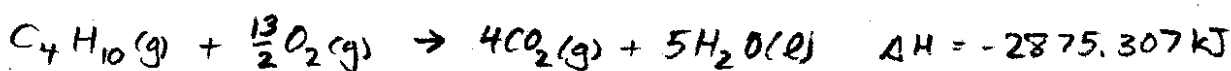
$$Q = 494549 \text{ J}$$

$$Q = 494.549 \text{ kJ}$$

$$\frac{494.549 \text{ kJ}}{10 \text{ g } C_4H_{10}} \times \frac{58.14 \text{ g } C_4H_{10}}{1 \text{ mol } C_4H_{10}} = 2875.307 \text{ kJ/mol } C_4H_{10}$$

$$\Delta H = -Q$$

$$\Delta H = -2875.307 \text{ kJ}$$



$$\Delta H = [4\Delta H^\circ_{CO_2(g)} + 5\Delta H^\circ_{H_2O(l)}] - [\Delta H^\circ_{C_4H_{10}(g)} + \frac{13}{2}\Delta H^\circ_{O_2(g)}]$$

$$-2875.307 \text{ kJ} = [4(-393.5 \text{ kJ}) + 5(-285.8 \text{ kJ})] - [\Delta H^\circ_{C_4H_{10}(g)} + \frac{13}{2}(0)]$$

$$\Delta H^\circ_{C_4H_{10}(g)} = -127.69 \text{ kJ}$$

4. Use Hess' Law to determine the heat of formation of p-nitrotoluene ( $C_7H_7O_2N$ ) given: - please answer in kcal

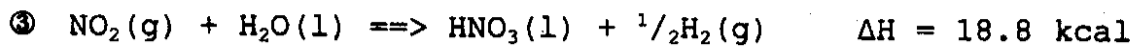
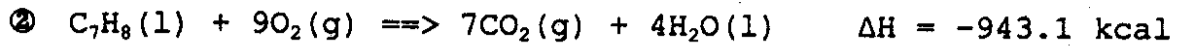
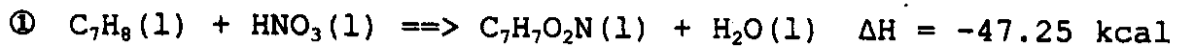
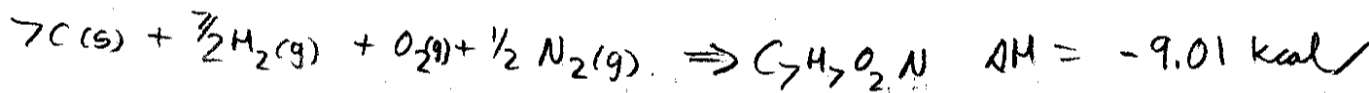
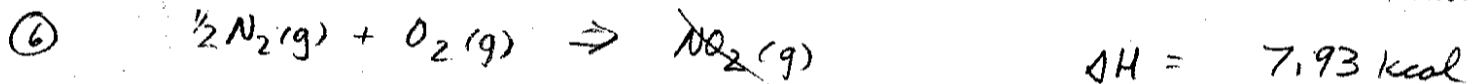
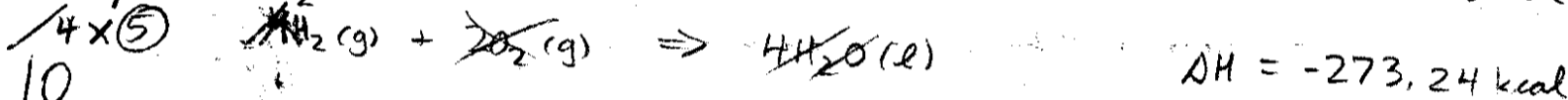
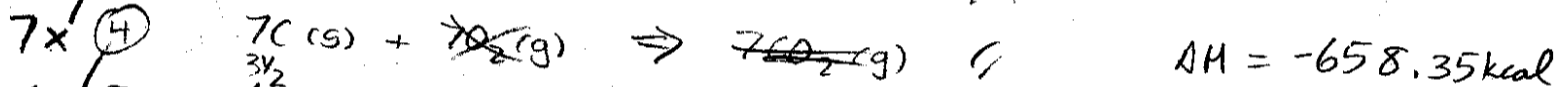
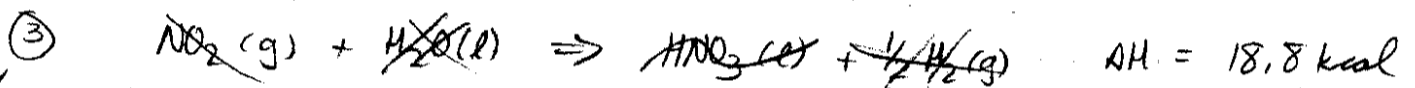
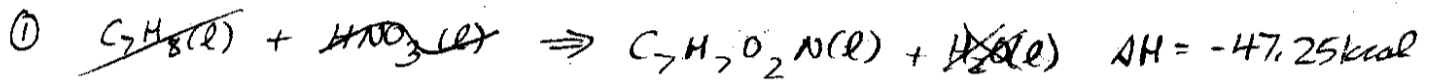


Table values for the formation reactions of  $CO_2(g)$ ,  $H_2O(l)$  and  $NO_2(g)$



Find  $7C(s) + \frac{7}{2}H_2(g) + O_2(g) + \frac{1}{2}N_2(g) \Rightarrow C_7H_7O_2N(l) \quad \Delta H = ?$



5. Calculate the amount of heat energy required to convert 355 g of ice at  $-25^{\circ}\text{C}$  to steam at  $250^{\circ}\text{C}$ . The following data should be of assistance:

Molar Heat of Fusion (melting) of Ice:  $6.02\text{ kJ/mol @ }0^{\circ}\text{C}$   
 Molar Heat of Vaporization of water:  $40.6\text{ kJ/mol @ }100^{\circ}\text{C}$   
 Specific Heat Capacity of Ice:  $4.69\text{ J/g}^{\circ}\text{C}$   
 Specific Heat Capacity of Water:  $4.184\text{ J/g}^{\circ}\text{C}$   
 Specific Heat Capacity of Steam:  $3.43\text{ J/g}^{\circ}\text{C}$   
 Answer:  $1291\text{ kJ}$

① Ice @  $-25^{\circ}\text{C} \rightarrow$  Ice at  $0^{\circ}\text{C}$

$$Q_1 = mc\Delta T$$

$$Q_1 = 355\text{g} \times 4.69\text{ J/g}^{\circ}\text{C} \times 25^{\circ}\text{C}$$

$$Q_1 = 41623.75\text{ J}$$

$$Q_1 = 41.624\text{ kJ}$$

② Ice @  $0^{\circ}\text{C} \rightarrow$  Water @  $0^{\circ}\text{C}$

$$Q_2 = L_f m$$

$$Q_2 = \left( \frac{6.02\text{ kJ}}{1\text{ mol}} \times \frac{1\text{ mol}}{18.02\text{ g}} \right) \times 355\text{ g}$$

$$Q_2 = 118.596\text{ kJ}$$

③ Water @  $0^{\circ}\text{C} \rightarrow$  Water @  $100^{\circ}\text{C}$

$$Q_3 = mc\Delta T$$

$$Q_3 = 355\text{g} \times 4.184\text{ J/g}^{\circ}\text{C} \times 100^{\circ}\text{C}$$

$$Q_3 = 148532\text{ J}$$

$$Q_3 = 148.532\text{ kJ}$$

④ Water @  $100^{\circ}\text{C} \rightarrow$  Steam @  $100^{\circ}\text{C}$

$$Q_4 = L_v m$$

$$Q_4 = \left( \frac{40.6\text{ kJ}}{1\text{ mol}} \times \frac{1\text{ mol}}{18.02\text{ g}} \right) \times 355\text{ g}$$

$$Q_4 = 799.834\text{ kJ}$$

⑤ Steam @  $100^{\circ}\text{C} \rightarrow$  Steam @  $250^{\circ}\text{C}$

$$Q_5 = mc\Delta T$$

$$Q_5 = 355\text{g} \times 3.43\text{ J/g}^{\circ}\text{C} \times 150^{\circ}\text{C}$$

$$Q_5 = 182647.5\text{ J}$$

$$Q_5 = 182.648\text{ kJ}$$

⑥  $Q_T = Q_1 + Q_2 + Q_3 + Q_4 + Q_5$

$$Q_T = 41.624\text{ kJ} + 118.596\text{ kJ} +$$

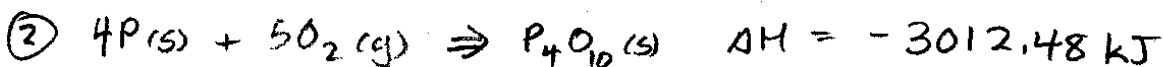
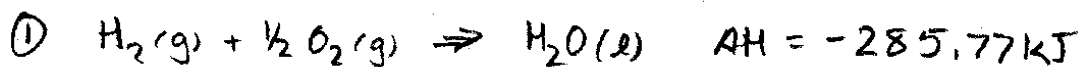
$$148.532\text{ kJ} + 799.834\text{ kJ} +$$

$$182.648\text{ kJ}$$

$$Q_T = 1291.123\text{ kJ}$$

6. From the following information, calculate  $\Delta H_{\text{H}_3\text{PO}_4(\text{aq})}^\circ$  in kJ - work in kJ

- a)  $\Delta H_{\text{H}_2\text{O}(\text{l})}^\circ = -285.77 \text{ kJ}$   
 b)  $\Delta H_{\text{P}_4\text{O}_{10}(\text{s})}^\circ = -3012.48 \text{ kJ}$   
 c) The natural form of phosphorus is P(s).  
 d) 13.5 g of  $\text{P}_4\text{O}_{10}(\text{s})$  is placed in exactly 1 L of water and an exothermic reaction proceeds in which  $\text{H}_3\text{PO}_4(\text{aq})$  is the only product. The temperature is observed to increase from  $15.03^\circ\text{C}$  to  $19.93^\circ\text{C}$ .  
 e) The specific heat capacity of water is  $4.184 \text{ J/g}^\circ\text{C}$ .  
 f) The answer is  $\Delta H_{\text{H}_3\text{PO}_4(\text{aq})}^\circ = -308.2 \text{ kcal}$



$Q = mc\Delta T$

$Q = 1000 \text{ g} \times 4.184 \text{ J/g}^\circ\text{C} \times (19.93 - 15.03)^\circ\text{C}$

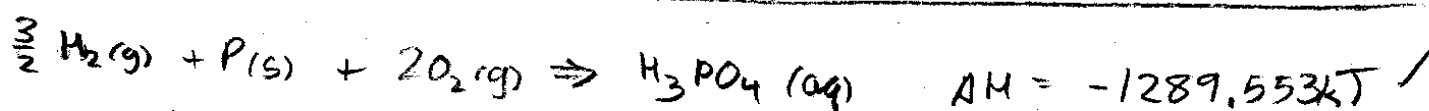
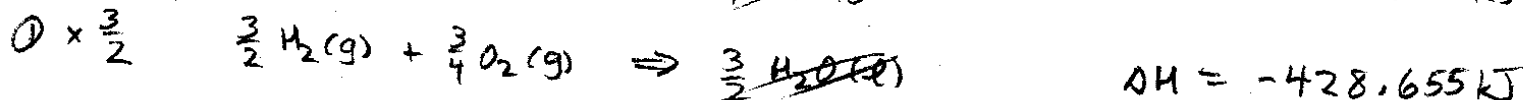
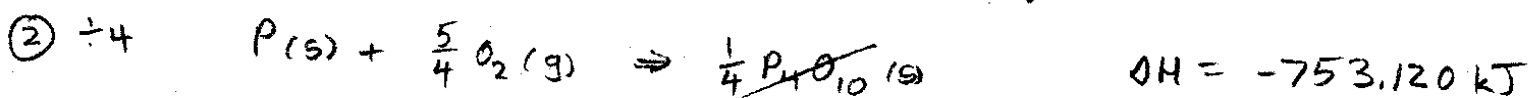
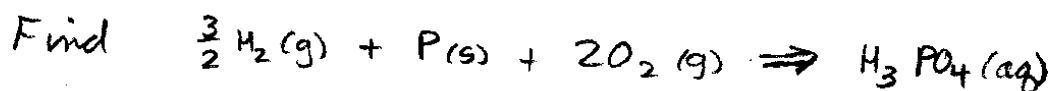
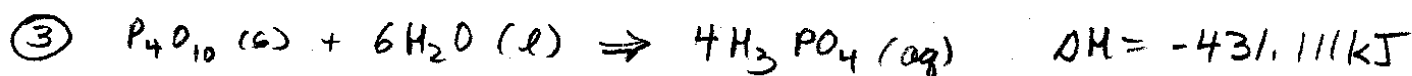
$Q = 20501.6 \text{ J}$

$Q = 20.502 \text{ kJ}$

$\frac{20.502 \text{ kJ}}{13.5 \text{ g P}_4\text{O}_{10}} \times \frac{283.88 \text{ g P}_4\text{O}_{10}}{1 \text{ mol P}_4\text{O}_{10}} = 431.111 \text{ kJ/mol P}_4\text{O}_{10}$

$\Delta H = -Q$

$\Delta H = -431.111 \text{ kJ}$



$-1289.553 \text{ kJ} \times \frac{1 \text{ kcal}}{4.184 \text{ kJ}} = -308.210 \text{ kcal}$  😊

**Bonus:**

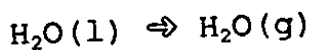
Given the following values at 25 °C and 1 atm pressure:

$$\begin{aligned}\Delta H_{\text{H}_2\text{O}(l)} &= -68.32 \text{ kcal} \\ \Delta H_{\text{H}_2\text{O}(g)} &= -57.80 \text{ kcal} \\ S_{\text{H}_2\text{O}(l)} &= 16.72 \text{ cal/K} \\ S_{\text{H}_2\text{O}(g)} &= 45.11 \text{ cal/K}\end{aligned}$$

And given:  $\Delta G = \Delta H - T\Delta S$

$\Delta G$  = Gibb's Free Energy ( $\Delta G \leq 0$  for spontaneity)  
 $\Delta H$  = Change in Enthalpy  
 $T$  = Temperature in Kelvins  
 $\Delta S$  = Change in Entropy

Calculate the temperature above which the physical change of



becomes spontaneous!!!

$$\Delta G = \Delta H - T\Delta S$$

for spontaneity

$$\Delta G \leq 0$$

$$\therefore 0 \geq \Delta H - T\Delta S$$

$$\therefore T\Delta S \geq \Delta H$$

$$T(S_2 - S_1) \geq (\Delta H_2 - \Delta H_1)$$

$$T(45.11 \text{ cal}_K - 16.72 \text{ cal}_K) \geq (-57.80 \text{ kcal} - (-68.32 \text{ kcal}))$$

$$T(28.39 \text{ cal}_K) \geq 10.52 \text{ kcal}$$

$$T(28.39 \text{ cal}_K) \geq 10520 \text{ cal}$$

$$T \geq 370.553 \text{ K}$$

$$T \geq 97.403^\circ\text{C} \quad \sim \text{close to } 100^\circ\text{C}$$

→ must substitute first  
to ensure division by  
zero does not occur

4

10