CHEMISTRY 114
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Worksheet 2

$N_2 + 2H_2 \rightarrow N_2H_{4(l)}$

1. Write the chemical equation for the formation of liquid hydrazine, $N_2H_4(l)$ and determine the standard heat of formation of liquid hydrazine, $N_2H_4(l)$ from the following data:

a) $2\ NH_3(g) + 3\ N_2O\ (g) \rightarrow 4N_2(g) + 3\ H_2O(l)$	$\Delta H^o = -1010$ kJ
b) $N_2O\ (g) + 3\ H_2(g) \rightarrow N_2H_4(l) + H_2O(l)$	-317 kJ
c) $2\ NH_3(g) + ½\ O_2(g) \rightarrow N_2H_4(l) + H_2O(l)$	-143 kJ
d) $H_2(g) + ½\ O_2(g) \rightarrow H_2O(l)$	-286 kJ

$3N_2O_{(g)} + 9H_{2(g)} \rightarrow 3N_2H_{4(l)} + 3H_2O_{(l)}$ 3(-317 kJ)

$3H_2O_{(l)} + 4N_{2(g)} \rightarrow 3N_2O_{(g)} + 2NH_{3(g)}$ +1010

$2NH_{3(g)} + \frac{1}{2}O_{2(g)} \rightarrow N_2H_{4(g)} + H_2O_{(l)}$ -143 kJ

$H_2O_{(l)} \rightarrow \frac{1}{2}O_{2(g)} + H_{2(g)}$ 286 kJ

$\frac{1}{4\,mol}(4N_{2(g)} + 8H_{2(g)} \rightarrow 4N_2H_{4(l)}$ +202 kJ)

$N_{2(g)} + 2H_{2(g)} \rightarrow N_2H_{4(l)}$ $\frac{202\,kJ}{4\,mol} = +50.5\,kJ/mol$

2. In liquid fuel rockets $N_2H_4(l)$ is the fuel and $N_2O_4(g)$ is the oxidant. Liquid water and nitrogen gas are the products. How much heat is liberated per mole of hydrazine? Take ΔH_f^o of $N_2O_4(g)$ to be 9 kJ mol^{-1}. (*Hint:* refer to problem 1)

$2N_2H_{4(l)} + N_2O_{4(g)} \rightarrow 3N_{2(g)} + 4H_2O_{(l)}$

$2N_2H_{4(l)} \rightarrow 4H_{2(g)} + 2N_{2(g)}$ 2(-50.5 kJ)

$N_2O_{4(g)} \rightarrow N_{2(g)} + 2O_{2(g)}$ -9 kJ

$4H_{2(g)} + 2O_{2(g)} \rightarrow 4H_2O_{(l)}$ 4(-286 kJ)

$2N_2H_{4(l)} + N_2O_{4(g)} \rightarrow 3N_{2(g)} + 4H_2O_{(l)}$ -1254 kJ

$\Delta H = \frac{-1254\,kJ}{2\,mol} = -627\,\frac{kJ}{mol}$

3. For a given substance why is its enthalpy of vaporization, measured at the normal boiling point, always greater than its enthalpy of fusion, measured at the normal boiling point?

Discuss intermolecular forces

4. The normal boiling point of liquid ammonia is 240 K. ΔH_{vap} at that temperature is 23.4 kJ mol^{-1}. The heat capacity of gaseous ammonia at constant pressure is 38 J K^{-1} mol^{-1}. Calculate q, w, ΔH, and ΔE for the following change in state: 2.00 mol NH_3 (l, 1 atm, 240 K) → 2.00 mol NH_3 (g, 1 atm, 298 K)

1) Vaporization

$\Delta H = (\Delta H_{vap})(mol) = (23.4 \frac{kJ}{mol})(2.00\ mol) = 46.8 kJ = ~~46800~~$

$W = -p\Delta V = -\Delta(pV) = -\Delta(nRT) = -RT(\Delta n) = -(8.31 \frac{J}{mol\,K})(240k)(2.00 mol) = -3988 J = -3.99kJ$

$q = \Delta H = 46.8 kJ$

$\Delta E = q + w = 46.8 kJ + -3.99 kJ = 42.8 kJ$

2) Heating

$(q = C_s m \Delta T)$

$q = C_p (mol) \Delta T = (38 \frac{J}{mol\,K})(2.00 mol)(58k) = 4408 J = 4.41 kJ$

$w = -p\Delta V = -\Delta(pV) = -\Delta(nRT) = -nR\Delta T = -(2.00 mol)(8.31 \frac{J}{mol\,K})(58k) = -963J = -0.963kJ$

$\Delta H = q = 4.41 kJ$

$\Delta E = q + w = 4.41 kJ + -0.963 kJ = 3.45 kJ$

5. Calculate the standard enthalpy of formation of methane, CH_4 (g), using a C-H bond enthalpy of 413 kJ mol^{-1} and the atomization enthalpies of 716.682 and 217.96 kJ mol^{-1}, respectively for C and H.

$C_{(s)} + 2H_{2(g)} \rightarrow CH_{4(g)}$

~~$\Delta H_f = (716.682 + 4(217.96 kJ)$~~

H–C(H)(H)–H

$\Delta H_f = (1 mol)(716.682 \frac{kJ}{mol}) + (4 mol)(217.96 \frac{kJ}{mol}) - 4(413 \frac{kJ}{mol}) = -64.16 kJ/mol$

Actual $\Delta H_f^\circ = -74.87 \frac{kJ}{mol}$

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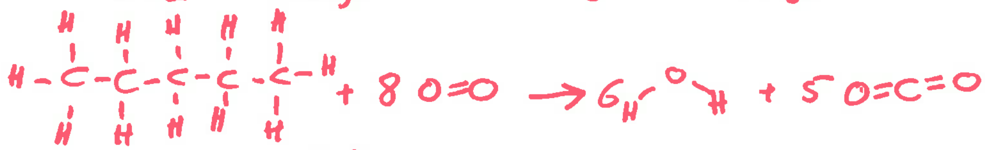
6. Use bond enthalpies (see the appropriate table in the textbook) to estimate ΔH^o when 1 mol of pentane ($CH_3CH_2CH_2CH_2CH_3$) is burned to CO_2 and gaseous water. (*Hint*: refresh the Lewis' dot structures)

$C_5H_{12} + 8O_{2(g)} \rightarrow 6H_2O_{(g)} + 5CO_{2(g)}$



breaking = 4(347kJ) + 12(414kJ) + 8(498kJ) = 10340kJ

forming = (5)(2)(799kJ) + (6)(2)(464kJ) = 13558kJ

ΔH ≈ (broken) + (formed) = 10340kJ − 13558kJ = −3218kJ

(Actual = −3509kJ)

7. A chemical system that is not an ideal gas is sealed in a strong, rigid container at room temperature and then heated vigorously

a) State whether ΔE, q and w are positive, negative or zero during the heating process.

+ ΔE

w = 0

+ q

b) Next the container is cooled to its original temperature. Determine the signs of ΔE, q and w for the cooling process.

− q

− ΔE

w = 0

c) Designate heating as step 1 and cooling as step 2. Determine the signs of $(\Delta E_1 + \Delta E_2)$, $(q_1 + q_2)$ and $(w_1 + w_2)$

ΔE = 0

w = 0

q = 0