Department of Chemistry
University of Texas at Austin

Name:____________________

Thermodynamics Unit - Enthalpy

1. Calculate the heat evolved from a reaction mixture of 13.4L SO_2 at 1 atm and 273K and 15 g of O_2.

$$2\,SO_2\,(g) + O_2\,(g) \rightarrow 2\,SO_3\,(g)\quad \Delta H^\circ = -198\text{kJ}$$

This is a limiting reagent problem. So we first need to calculate the moles of each reactant:

$$n_{O_2} = \frac{15g}{32\frac{g}{mol}} = 0.469 moles$$

$$n_{SO_2} = \frac{PV}{RT} = \frac{(1atm)(13.4L)}{(0.08206\frac{L \bullet atm}{molK})(273K)} = 0.598 moles$$

Now we divide the number of moles by the species' stoichiometric coefficient:

$$\frac{n_{O_2}}{1} > \frac{n_{SO_2}}{2}$$

$$\frac{0.469mol}{1} > \frac{0.598mol}{2}$$

$$0.469 > 0.299$$

So SO_2 is the limiting reactant. It will dictate how far the reaction can proceed.
Now we can actually calculate the ΔH of this particular situation. The value ΔH° refers to exactly 1 mol of O_2 reacting with 2 mol of SO_2. So, now we have to scale this ΔH° to our reaction, which only has 0.598 mol of SO_2.

$$\Delta H = n\Delta H^\circ$$

$$\Delta H = (0.598 molSO_2)(\frac{1molrxn}{2molSO_2})(-\frac{198kJ}{1molrxn})$$

$$\Delta H = -59.202kJ$$

2. The oxidation of nitrogen in the hot exhaust of jet engines and automobile engines occurs by the reaction

$$N_2\,(g) + O_2\,(g) \rightarrow 2\,NO\,(g)\quad \Delta H^\circ = +180.6\text{ kJ}$$

a. How much heat is absorbed by the formation of 1.55 mol of NO?

The given ΔH° value is the standard heat of formation that corresponds to 1 mole reaction, which forms 2 moles of NO according to the written chemical equation. So again, we have to tailor the given information to our reality which is 1.55 mol of NO.

$$\Delta H = n\Delta H^\circ$$

$$\Delta H = (1.55 molNO)(\frac{1molrxn}{2molNO})(\frac{180.6kJ}{1molrxn})$$

$$\Delta H = 139.97kJ$$

b. How much heat is absorbed by the reaction of 5.45 L of nitrogen measured at 1.00 atm and 273K? (R=0.08206 L*atm*mol^{-1}*K^{-1})

First we need to determine how many moles of N_2 are present in this situation in order to carry out an analysis similar to part a.

$$n = \frac{PV}{RT}$$

$$n = \frac{(1atm)(5.45L)}{(0.08206\frac{L \bullet atm}{molK})(273K)}$$

$$n = 0.243mol$$

$$\Delta H = n\Delta H^{\circ}$$

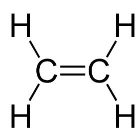
$$\Delta H = (0.243molN_2)(\frac{1molrxn}{1molN_2})(\frac{180.6kJ}{1molrxn})$$

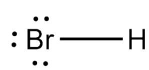
$$\Delta H = 43.9kJ$$

3. Estimate the heat released when ethene (CH_2=CH_2) reacts with HBr to give CH_3CH_2Br. Bond enthalpies are C-H: 412 kJ/mol, C-C: 348 kJ/mol, C=C: 612 kJ/mol, C-Br: 276 kJ/mol, Br-Br: 193kJ/mol, H-Br: 366 kJ/mol.

First draw out the reactants and products to analyze the bond types.

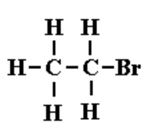
Reactants:





4 C-H bonds 1 C=C bond 1 H-Br bond

Products:



5 C-H bonds 1 C-C bond 1 C-Br bond

Work:

$$\Delta H = \sum nBE_{react} - \sum nBE_{prod}$$

$$\Delta H = [4(412\tfrac{kJ}{mol}) + 1(612\tfrac{kJ}{mol}) + 1(366\tfrac{kJ}{mol})] - [5(412\tfrac{kJ}{mol}) + 1(348\tfrac{kJ}{mol}) + 1(276\tfrac{kJ}{mol})]$$

$$\Delta H = -58\tfrac{kJ}{mol}$$

4. Calculate the standard reaction enthalpy for the reaction of calcite with hydrochloric acid: $CaCO_3(s) + 2HCl(aq) \rightarrow CaCl_2(aq) + H_2O(l) + CO_2(g)$. The standard enthalpies of formation for $CaCO_3(s)$: -1206.9 kJ/mol, $CaCl_2(aq)$: -877.1 kJ/mol, HCl(aq): - 167.16 kJ/mol, $H_2O(l)$: -285.83 kJ/mol, $CO_2(g)$: -393.51 kJ/mol.

Work:

$$\Delta H = \sum n\Delta_f H_{prod} - \sum n\Delta_f H_{react}$$

$$\Delta H = [1(-877.1\tfrac{kJ}{mol}) + 1(-285.83\tfrac{kJ}{mol}) + 1(-393.51\tfrac{kJ}{mol})] - [1(-1206.9\tfrac{kJ}{mol}) + 2(-167.16\tfrac{kJ}{mol})]$$

$$\Delta H = -15.22\tfrac{kJ}{mol}$$

5. Which of the following reactions is an enthalpy of formation reaction?

a. $CH_4(g) + 2O_2(g) \rightarrow CO_2(g) + 2H_2O(l)$ (No-CH_4 is NOT an element)

b. $2Fe(s) + 3/2O_2(g) \rightarrow Fe_2O_3(s)$ (Yes-Both reactants are elements in their standard states!)

c. $C_{diamond}(s) + 2H_2(g) \rightarrow CH_4(g)$ (No-C in its standard state is $C_{graphite}$)

d. $Hg(s) + ½O_2(g) \rightarrow HgO(s)$ (No-Hg in its standard state is Hg (l))

6. Calculate the change in enthalpy for the combustion of graphite by first stating the combustion reaction and then using the data below.

$H_2(g) + ½O_2(g) \rightarrow H_2O(l)$; ΔH = -285.83 kJ/mol

$CO_2(g) + 2H_2O(l) \rightarrow CH_4(g) + 2O_2(g)$; ΔH = 882.00 kJ/mol

$C_{graphite}(s) + 2H_2(g) \rightarrow CH_4(g)$; ΔH = -74. kJ/mol

General Combustion Reaction of Hydrocarbons:

__Fuel (hydrocarbon) + __O_2 (g) → __CO_2 (g) + __H_2O (l)

Combustion Reaction of Graphite:

$C_{graphite}$ (s) + O_2 (g) → CO_2 (g)

There is no water on products side because there are no hydrogens in the reactants.

Rxn 1 – Flipped and x2: ~~$2H_2O(l)$~~ → ~~$2H_2(g)$~~ + ~~$1O_2(g)$;~~ ΔH = +571.66 kJ/mol

Rxn 2 – Flipped: ~~$CH_4(g)$~~ + ~~2~~1$O_2(g)$ → $CO_2(g)$ + ~~$2H_2O(l)$~~; ΔH = -882.00 kJ/mol

Rxn 3 – Same: $C_{graphite}(s)$ + ~~$2H_2(g)$~~ → ~~$CH_4(g)$~~; ΔH = -74 kJ/mol

OVERALL: **$C_{graphite}$ (s) + O_2 (g) → CO_2 (g); ΔH = -384.34 kJ/mol**

7. Which of $O_2(g)$, $O_2(l)$, $H_2(g)$, $H_2(l)$, $H_2O(g)$, $H_2O(l)$ have a heat of formation equal to zero?

$O_2(g)$ and $H_2(g)$ because these are both in their elemental form under standard conditions.

Name:____________________

8. Calculate the reaction enthalpy for the formation of anhydrous aluminum chloride by first stating the formation reaction and then using the data below:
$2Al(s) + 6HCl(aq) \rightarrow 2AlCl_3(aq) + 3H_2(g)$; ΔH = -149 kJ/mol
$HCl(g) \rightarrow HCl(l)$; ΔH = -74 kJ/mol
$H_2(g) + Cl_2(g) \rightarrow 2HCl(g)$; ΔH = -185 kJ/mol
$AlCl_3(s) \rightarrow AlCl_3(aq)$; ΔH = -323 kJ/mol

A few things to remember about formation reactions:

- Formation reactions only have elements in their standard form as reactants
- The product is the desired compound being formed

Anhydrous aluminum chloride's formula is $AlCl_3$ (s). Also, we will treat HCl (aq) as synonymous to HCl (l).

Chemical Reaction:

$Al(s) + (3/2)Cl_2(g) \rightarrow AlCl_3(s)$ **OR** $2Al(s) + 3Cl_2(g) \rightarrow 2AlCl_3(s)$

Rxn1 – Same: $2Al(s)$ + ~~$6HCl(aq)$~~ → ~~$2AlCl_3(aq)$~~ + ~~$3H_2(g)$~~; ΔH = -149 kJ/mol

Rxn 2 – X6: ~~$6HCl(g)$~~ → ~~$6HCl(l)$~~; ΔH = -444 kJ/mol

Rxn 3 – X3: ~~$3H_2(g)$~~ + $3Cl_2(g)$ → ~~$6HCl(g)$~~; ΔH = -555 kJ/mol

Rxn 4 – Flipped and x2: ~~$2AlCl_3(aq)$~~ → $2AlCl_3(s)$; ΔH = 646 kJ/mol

OVERALL: **$2Al(s) + 3Cl_2(g) \rightarrow 2AlCl_3(s)$; ΔH = -502 kJ/mol**