Molar Enthalpies of Formation
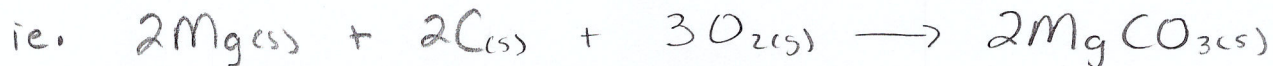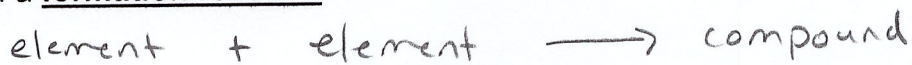
- Every compound can be formed from its basic elements. This type of reaction is called a **formation reaction**
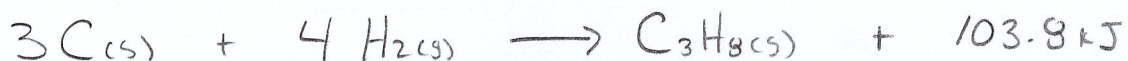
$$element + element \longrightarrow compound$$

ie. $2Mg_{(s)} + 2C_{(s)} + 3O_{2(g)} \longrightarrow 2MgCO_{3(s)}$

- Therefore, every compound has a **standard molar enthalpy of formation (Δ_fH^o)** which represent the amount of energy required or released when 1 mole of compound is formed from its elements.
    - A list of some common compounds and their corresponding molar enthalpies of formation are found on pg. 4-5 of the data book.
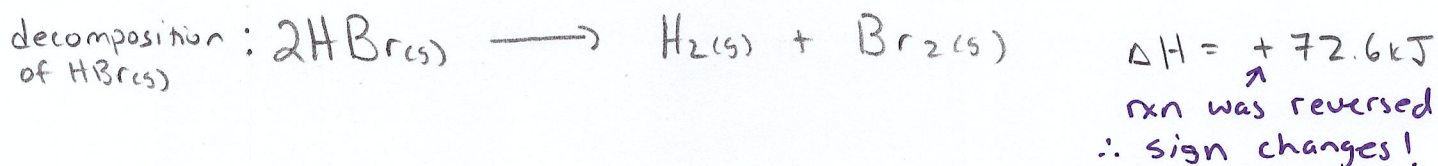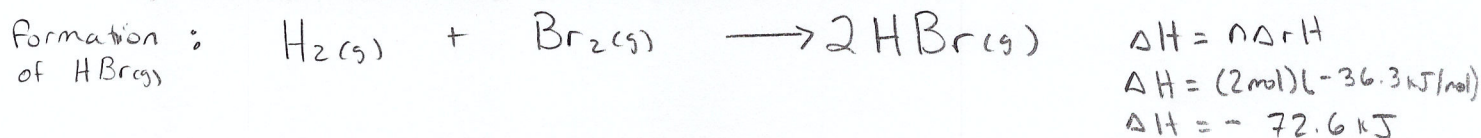   - Example:

    $\Delta_fH^o = -103.8\ kJ/mol$ for C_3H_8

    $$3C_{(s)} + 4H_{2(g)} \longrightarrow C_3H_{8(s)} + 103.8\ kJ$$

- Recall, the reverse process of a formation reaction is a **decomposition reaction** (ie. a compound breaking down into its elements) compound $\longrightarrow$ element + element

Formation of $HBr_{(g)}$: $H_{2(g)} + Br_{2(g)} \longrightarrow 2HBr_{(g)}$

$\Delta H = n \Delta_r H$
$\Delta H = (2\ mol)(-36.3\ kJ/mol)$
$\Delta H = -72.6\ kJ$

decomposition of $HBr_{(g)}$: $2HBr_{(g)} \longrightarrow H_{2(g)} + Br_{2(s)}$

$\Delta H = +72.6\ kJ$
↑
rxn was reversed
∴ sign changes!

- We can use standard molar enthalpies of formation (Δ_fH^o) values to calculate the enthalpy change (ΔH) for *any given reaction* using the following equation:

not just for formation or decomposition rxns!

looks similar to $\Delta H = n \Delta_r H$!

↙ means "sum of" or "total"

$$\Delta H^o = \sum(n \cdot \Delta_fH^o) - \sum(n \cdot \Delta_fH^o)$$
    products   reactants

where   n is the number of moles as found in the <u>balanced</u> reaction (mol)

Δ_fH^o is the molar enthalpy of formation of a *compound* (kJ/mol)
↳ from data booklet (pg. 4 & 5)

✳ - When using this formula, the standard molar enthalpies of formation for <u>all</u> <u>elements</u> at SATP have a value of zero because elements can't undergo a formation reaction
    - $\Delta_fH^o = 0$ for any element (ie, C, H_2, Ag)

- The phase (solid, liquid, or gas) of a compound is important because a different phase will change the standard molar enthalpy of formation ($\Delta_f H°$) for that compound
 - Example:

$$H_2O_{(l)} : \Delta_f H° = -285.8 \text{ kJ/mol}$$

$$H_2O_{(g)} : \Delta_f H° = -241.8 \text{ kJ/mol}$$

✳ - Calculating the enthalpy change for any given reaction using *standard molar enthalpies of formation* is useful when you feel like you are missing information and all you have, or can create, is a balanced reaction!
  - Hess's Law is good to use when calculating the enthalpy change for a reaction and a list of intermediate reactions are given

EXAMPLES:
  1. Calculate the standard enthalpy change for the following reaction.

$$CaO_{(s)} + H_2O_{(l)} \rightarrow Ca(OH)_{2(s)} \qquad \Delta H° = ?$$
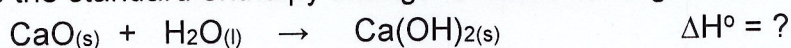
$$\Delta H° = \underset{products}{\sum(n \cdot \Delta_f H°)} - \underset{reactants}{\sum(n \cdot \Delta_f H°)}$$

$$\Delta H = \underset{\substack{Ca(OH)_2 (s) \\ \text{sum of all} \\ \text{Products}}}{[(n \cdot \Delta_f H°)]} - \underset{\substack{CaO_{(s)} \qquad\qquad H_2O_{(l)} \\ \text{sum of all reactants}}}{[(n \cdot \Delta_f H°) + (n \cdot \Delta_f H°)]}$$

$$\Delta H = \underset{Ca(OH)_{2(s)}}{[(1mol)(-985.2 \text{ kJ/mol})]} - \underset{CaO_{(s)}}{[(1mol)(-634.9 \text{ kJ/mol})} + \underset{H_2O_{(l)}}{(1mol)(-285.8 \text{ kJ/mol})]}$$

$$\Delta H = [-985.2 \text{ kJ}] - [-920.7 \text{ kJ}]$$

$$\boxed{\Delta H = -64.5 \text{ kJ}}$$

2. Use the following chemical reaction to calculate the molar enthalpy change for nitrogen dioxide.

$$\Delta_r H = ?$$

$$2\ NO_{(g)}\ +\ O_{2(g)}\ \rightarrow\ 2\ NO_{2(g)}$$

$$\Delta H = n \Delta_r H \quad ②$$

$$\downarrow$$

$$\Delta H° = \Sigma (n \cdot \Delta_f H°) - \Sigma (n \cdot \Delta_f H°) \quad ①$$
$$\quad\quad\quad prod. \quad\quad\quad\quad react.$$
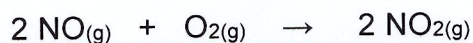
① $\Delta H° = [(2\,mol)(+33.2\,kJ/mol)] - [(2\,mol)(+91.3\,kJ/mol) + 0\,kJ/mol]$
$$\quad\quad\quad\quad NO_{2(g)} \quad\quad\quad\quad\quad\quad\quad NO_{(g)} \quad\quad\quad\quad\quad\quad O_{2(g)}$$

$$\Delta H° = -116.2\,kJ$$

② $\Delta H = n \Delta_r H \quad \rightarrow \quad \Delta_r H = \dfrac{\Delta H}{n}$

$$\Delta_r H = \dfrac{-116.2\,kJ}{2\,mol} = -58.1\,kJ/mol$$
$$\quad\quad\quad\quad\quad\quad\quad\quad \leftarrow \text{from balanced rxn}$$

$$\boxed{\Delta_r H = -58.1\,kJ/mol}$$

Now try pg. 382 # 8-10 & Practice Problem #1-3

3. The fertilizer urea ($CO(NH_2)_2$) is produced along with liquid water by the reaction of ammonia and carbon dioxide. If the molar enthalpy change for urea ($CO(NH_2)_2$) is -134.0kJ/mol, calculate the standard molar enthalpy of formation for urea ($CO(NH_2)_2$)?

↳ $\Delta_f H° = ?$

* need to work backwards!

for the rxn, NOT the formation rxn.

$\Delta_r H = -134.0 \, kJ/mol$
$CO(NH_2)_2$

$$2NH_{3(g)} + CO_{2(s)} \longrightarrow CO(NH_2)_{2(s)} + H_2O_{(\ell)}$$

② $\Delta H = \sum(n \cdot \Delta_f H°) - \sum(n \cdot \Delta_f H°)$
   prod.   react.
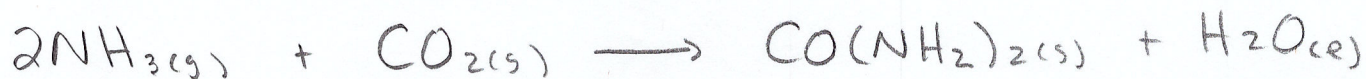
$\Delta H = n \Delta_r H$ ①

① $\Delta H = n \Delta_r H = (1 \, mol)(-134.0 \, kJ/mol) = -134.0 \, kJ$

② $\Delta H° = \sum(n \cdot \Delta_f H°) - \sum(n \cdot \Delta_f H°)$
   prod.   react.

sum of products ↙

$-134.0 \, kJ = [(1 mol)(\Delta_f H°) + (1 mol)(-285.8 \, kJ/mol)]$
                  $CO(NH_2)_2$ $H_2O_{(\ell)}$

sum of reactants →

$- [(2 mol)(-45.9 \, kJ/mol) + (1 mol)(-393.5 \, kJ/mol)]$
   $NH_{3(s)}$ $CO_{2(s)}$

$-134.0 \, kJ = [(1 mol)(\Delta_f H°) - 285.8 \, kJ] - [-485.3 \, kJ]$
                  products   reactants

$-619.3 \, kJ = (1 mol)(\Delta_f H°) - 285.8 \, kJ$

$-333.5 \, kJ = (1 mol)(\Delta_f H°)$

$\boxed{-333.5 \, kJ/mol = \Delta_f H°}$

Now try pg. 383 # 11-12 & Practice Problem #4

Practice Problems

1. How much energy is released when 2 mol of potassium chlorate is formed?

2. When 1 mol of tin(II) oxide decomposes, ___i___ of energy is ___ii___.

   The statement above is correctly completed by information in row

Row	i	ii
a.	280.7 kJ	released
b.	280.7 kJ	absorbed
c.	557.6 kJ	released
d.	557.6 kJ	absorbed

3. What is the enthalpy change for the combustion of pentane (C_5H_{12}) in an open system?

4. Given that the molar enthalpy change of combustion for propan-1-ol (C_3H_7OH) is -2021 kJ/mol in a closed system, what is the molar enthalpy of formation for propan-1-ol?

Answers

1. 795.4 kJ of energy is released
2. B
3. -3244.8 kJ
4. -302.7 kJ/mol