

## Standard Enthalpy of Formation (or Heat of Formation).

Previously, you were given the formula  $\Delta H_{\text{rxn}} = H_{\text{products}} - H_{\text{reactants}}$ . Scientists have trouble determining the exact value of enthalpy of a substance. It is similar to determining the height of a mountain. They will use a specific reference point for enthalpy just like sea level is height zero for mountain height. This "sea level" reference point for all enthalpy expressions is called the standard enthalpy (heat) of formation  $\Delta H_f^\circ$ .

**Standard heat of formation is defined as the heat of reaction when one mole of a compound is formed from its free elements at 1 atm and 25°C (standard state). 1 atm and 25°C is called standard thermodynamic conditions.**

$\Delta H_f^\circ$  values are given in the table (right). More are in the back of your textbook.  $\Delta H$  is temperature dependent and changes only with a change in temperature.

**Note:**  $\Delta H_f^\circ$  of any free elements in its most stable form is 0. (See

table). Notice that for allotropes,  $\Delta H_f^\circ$  is 0 for the most stable form of the element). For ozone  $\text{O}_3$ ,  $\Delta H_f^\circ$  is 142.2 kJ/mole; for  $\text{O}_2$   $\Delta H_f^\circ$  is 0 kJ/mole.

Similarly, C(graphite)  $\Delta H_f^\circ = 0$ ; C(diamond)  $\Delta H_f^\circ = 1.90$  kJ/mole.

**Note: in general, compounds with negative  $\Delta H_f^\circ$  values are more stable than those with positive  $\Delta H_f^\circ$  values.**

### Some important points:

- $\Delta H_f^\circ$  is always given per mole of compound formed.
- $\Delta H_f^\circ$  involves formation of a compound from its elements with the substances in their standard states.
- Standard state conditions are:

#### **For an element:**

- It is the form that the element exists in at 25°C and 1 atmosphere. The element in its standard state is called a **free element**.

#### **For a compound:**

- For a gas it is a pressure of exactly 1 atmosphere.
- For a substance in solution, it is a concentration of exactly 1 M.
- For a pure solid or liquid, it is the pure solid or liquid.

- $\Delta H_f^\circ$  for an element in its standard state (such as  $\text{Ba}_{(s)}$  or  $\text{N}_{2(g)}$ ) equals 0.

### Reactions showing the heats of formation:

The reaction for the heat of formation of  $\text{H}_2\text{O}_{(g)}$  is:



Notice the different values of  $\Delta H_f^\circ$ . For compounds in different states (water as a gas, and as a liquid).  $\Delta H_f^\circ$  is a state function.  $\Delta H_f^\circ \text{H}_2\text{O}_{(g)} = -241.8$  kJ/mol;  $\Delta H_f^\circ \text{H}_2\text{O}_{(l)} = -285.8$  kJ/mole.

Also notice that because only 1 mole of a compound is formed from its free elements, Fractional coefficients are used in  $\Delta H_f^\circ$  equations and other thermochemical equations. They are **never** used in the regular balancing of equations throughout the course.

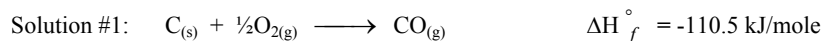


**Standard Enthalpies of Formation of Some Inorganic Substances at 25°C**

SUBSTANCE	$\Delta H_f^\circ$ (kJ/mol)	SUBSTANCE	$\Delta H_f^\circ$ (kJ/mol)
Ag(s)	0	$\text{H}_2\text{O}_2(l)$	-187.6
AgCl(s)	-127.04	Hg(l)	0
Al(s)	0	$\text{I}_2(s)$	0
$\text{Al}_2\text{O}_3(s)$	-1669.8	HI(g)	25.94
$\text{Br}_2(l)$	0	Mg(s)	0
HBr(g)	-36.2	MgO(s)	-601.8
C(graphite)	0	$\text{MgCO}_3(s)$	-1112.9
C(diamond)	1.90	$\text{N}_2(g)$	0
CO(g)	-110.5	$\text{NH}_3(g)$	-46.3
CO <sub>2</sub> (g)	-393.5	NO(g)	90.4
Ca(s)	0	NO <sub>2</sub> (g)	33.85
CaO(s)	-635.6	$\text{N}_2\text{O}_4(g)$	9.66
$\text{CaCO}_3(s)$	-1206.9	$\text{N}_2\text{O}(g)$	81.56
$\text{Cl}_2(g)$	0	O(g)	249.4
HCl(g)	-92.3	$\text{O}_2(g)$	0
Cu(s)	0	$\text{O}_3(g)$	142.2
CuO(s)	-155.2	S(rhombic)	0
$\text{F}_2(g)$	0	S(monoclinic)	0.30
HF(g)	-268.61	$\text{SO}_2(g)$	-296.1
H(g)	218.2	$\text{SO}_3(g)$	-395.2
$\text{H}_2(g)$	0	$\text{H}_2\text{S}(g)$	-20.15
$\text{H}_2\text{O}(g)$	-241.8	ZnO(s)	-347.98
$\text{H}_2\text{O}(l)$	-285.8		

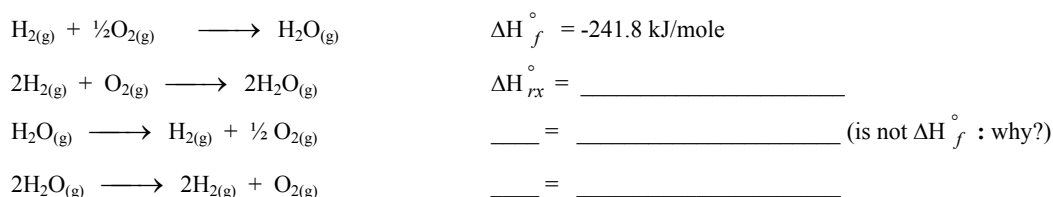
Write the heat of formation reaction for each of the following compounds. Include the heat of formation value as shown in the example below. See P. A-21 of Appendix 4 in the back of the book for the additional values.

- |                                |                                  |
|--------------------------------|----------------------------------|
| 1. $\text{CO}_{(g)}$           | 6. $\text{SO}_{2(g)}$            |
| 2. $\text{Ag}_2\text{O}_{(s)}$ | 7. $\text{SO}_{3(g)}$            |
| 3. $\text{NaCl}_{(s)}$         | 8. $\text{Ca}(\text{OH})_{2(s)}$ |
| 4. $\text{NaClO}_{3(s)}$       | 9. $\text{Fe}_2\text{O}_{3(s)}$  |
| 5. $\text{NO}_{(g)}$           | 10. $\text{MgO}_{(s)}$           |



The total heat of any reaction can be expressed as  $\Delta H_{rx}^\circ$  - called the standard enthalpy (heat) of reaction carried out at 1 atm and 25 °C. You will use the  $\Delta H_f^\circ$  values to find  $\Delta H_{rx}^\circ$ .

Ex: Given the following heat of formation reaction, fill in the remaining values as  $\Delta H_f^\circ$  or  $\Delta H_{rx}^\circ$ .



Standard heats of formation can be used to calculate the heat of reaction  $\Delta H_{rx}^\circ$  for any reaction carried out at 1 atm. THIS IS CALLED THE DIRECT METHOD OF FINDING :  $\Delta H_{rx}^\circ$ .

$$\Delta H_{rx}^\circ = \sum n \Delta H_f^\circ (\text{products}) - \sum n \Delta H_f^\circ (\text{reactants}) \quad \text{where } \Sigma = \text{sum of; } n = \text{moles}$$

Ex. 1 Calculate the heat of reaction for the formation of carbon dioxide from carbon monoxide gas and oxygen. (use the  $\Delta H_f^\circ$  table); remember,  $\Delta H_f^\circ$  of free elements = 0. (-566.0 kJ)

Ex. 2: Benzene  $\text{C}_6\text{H}_6$  is an important hydrocarbon. Find the heat of reaction for the combustion of benzene  $\text{C}_6\text{H}_{6(l)}$ :  
 $\Delta H_f^\circ$  (benzene) = +49.0 kJ/mole. (-6270 kJ)

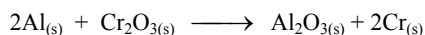
Ex. 3: The heat of formation for sulfur dioxide gas is -297.2 kJ/mol. How many kJ of energy are given off when 25.0 grams of  $\text{SO}_{2(g)}$  is produced from its elements? (116 kJ)

**PROBLEMS:**

1. Using the standard enthalpies in the table 2 pages back, calculate the standard change in enthalpy for the thermite reaction: **powdered aluminum metal and solid iron (III) oxide produces solid aluminum oxide and iron metal.**

This reaction occurs when a mixture of powdered aluminum and iron (III) oxide is ignited with a magnesium fuse. (If you need any other  $\Delta H_f^\circ$  values use the appendix in the text.) (-850)

2. The “thermite reaction” above is one in which molten iron is made from the reaction of aluminum powder and iron oxide. A variation on that reaction was described in October 1984 Journal of Chemical Education. The reaction is:



- (a) Calculate  $\Delta H$  for this reaction. (-548 kJ)

- (b) Which reaction yields more energy **per gram of metal formed**, the thermite reaction in #1 above, or this one?

3. Methanol ( $\text{CH}_3\text{OH}$ ) is often used as a fuel in high-performance engines in race cars. Compare the standard enthalpy of combustion per gram of methanol with that per gram of gasoline. Gasoline is actually a mixture of compounds, but assume for this problem that gasoline is pure liquid octane ( $\text{C}_8\text{H}_{18}$ ) (-22.7, -48.7, -1454,  $-1.09 \times 10^4$ )

**DO ASSIGNMENT #4 ON ASSIGNMENT SHEET  
P285-286 #59, 60, 61, 65, 79.**