Standard Enthalpy of Formation (or Heat of Formation).

Previously, you were given the formula $\mathbf{\Delta H_{rxn} = H_{products} - H_{reactants}}$. 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 $\mathbf{\Delta H^{\circ}_f}$ **.**

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.

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

Note: ΔH°_f of any free elements in its most stable form is 0. (See table). Notice that for allotropes, ΔH°_f is 0 for the most stable form of the element). For ozone O_3, ΔH°_f is 142.2 kJ/mole; for O_2 ΔH°_f is 0 kJ/mole.

Similarly, C(graphite) ΔH°_f = 0; C(diamond) ΔH°_f = 1.90 kJ/mole.

Note: in general, compounds with negative ΔH°_f values are more stable than those with positive ΔH°_f values.

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

SUBSTANCE	ΔH°_f (kJ/mol)	SUBSTANCE	ΔH°_f(kJ/mol)
Ag(*s*)	0	$H_2O_2(l)$	−187.6
AgCl(*s*)	−127.04	Hg(*l*)	0
Al(*s*)	0	$I_2(s)$	0
$Al_2O_3(s)$	−1669.8	HI(*g*)	25.94
$Br_2(l)$	0	Mg(*s*)	0
HBr(*g*)	−36.2	MgO(*s*)	−601.8
C(graphite)	0	$MgCO_3(s)$	−1112.9
C(diamond)	1.90	$N_2(g)$	0
CO(*g*)	−110.5	$NH_3(g)$	−46.3
$CO_2(g)$	−393.5	NO(*g*)	90.4
Ca(*s*)	0	$NO_2(g)$	33.85
CaO(*s*)	−635.6	$N_2O_4(g)$	9.66
$CaCO_3(s)$	−1206.9	$N_2O(g)$	81.56
$Cl_2(g)$	0	O(*g*)	249.4
HCl(*g*)	−92.3	$O_2(g)$	0
Cu(*s*)	0	$O_3(g)$	142.2
CuO(*s*)	−155.2	S(rhombic)	0
$F_2(g)$	0	S(monoclinic)	0.30
HF(*g*)	−268.61	$SO_2(g)$	−296.1
H(*g*)	218.2	$SO_3(g)$	−395.2
$H_2(g)$	0	$H_2S(g)$	−20.15
$H_2O(g)$	−241.8	ZnO(*s*)	−347.98
$H_2O(l)$	−285.8		

Some important points:

1. ΔH°_f is always given per mole of $_{compound}$ formed.
2. ΔH°_f involves formation of a compound from its elements with the substances in their standard states.
3. 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.
4. ΔH°_f for an element in its standard state (such as $Ba_{(s)}$ or $N_{2(g)}$) equals 0.

Reactions showing the heats of formation:

The reaction for the heat of formation of $H_2O_{(g)}$ is:

$$H_{2(g)} + \tfrac{1}{2} O_2(g) \longrightarrow H_2O(g) \qquad \Delta H^{\circ}_f = -241.8 \text{ kJ/mole}$$

Notice the different values of ΔH°_f **.** For compounds in different states (water as a gas, and as a liquid). ΔH°_f is a state function. ΔH°_f $H_2O_{(g)}$ = -241.8 kJ/mol; ΔH°_f $H_2O_{(l)}$ = -285.8 kJ/mole.

Also notice that because only 1 mole of a compound is formed form its free elements, Fractional coefficients are used in ΔH°_f equations and other thermochemical equations. They are **never** used in the regular balancing of equations throughout the course.

$$H_{2(g)} + \tfrac{1}{2}O_{2(g)} \longrightarrow H_2O_{(g)} \qquad \Delta H^{\circ}_f = -241.8 \text{ kJ/mole}$$

$$H_{2(g)} + \tfrac{1}{2}O_{2(g)} \longrightarrow H_2O_{(l)} \qquad \Delta H^{\circ}_f = -285.8 \text{ kJ/mole}$$

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. $CO_{(g)}$
2. $Ag_2O_{(s)}$
3. $NaCl_{(s)}$
4. $NaClO_{3(s)}$
5. $NO_{(g)}$)
6. $SO_{2(g)}$
7. $SO_{3(g)}$
8. $Ca(OH)_{2(s)}$
9. $Fe_2O_{3(s)}$
10. $MgO_{(s)}$

Solution #1: $C_{(s)} + \frac{1}{2}O_{2(g)} \longrightarrow CO_{(g)}$ ΔH°_f = -110.5 kJ/mole

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The total heat of any reaction can be expressed as ΔH°_{rx} - called the standard enthalpy (heat) of reaction carried out at 1 atm and 25 °C. You will use the ΔH°_f values to find ΔH°_{rx} .

Ex: Given the following heat of formation reaction, fill in the remaining values as ΔH°_f or ΔH°_{rx} .

$H_{2(g)} + \frac{1}{2}O_{2(g)} \longrightarrow H_2O_{(g)}$ ΔH°_f = -241.8 kJ/mole

$2H_{2(g)} + O_{2(g)} \longrightarrow 2H_2O_{(g)}$ ΔH°_{rx} = ______________________

$H_2O_{(g)} \longrightarrow H_{2(g)} + \frac{1}{2} O_{2(g)}$ ____ = ______________________ (is not ΔH°_f **: why?)**

$2H_2O_{(g)} \longrightarrow 2H_{2(g)} + O_{2(g)}$ ____ = ______________________

Standard heats of formation can be used to calculate the heat of reaction ΔH°rx for any reaction carried out at 1 atm. THIS IS CALLED THE DIRECT METHOD OF FINDING : ΔH°_{rx} .

$$\Delta H^\circ_{rx} = \Sigma n\Delta H^\circ_{f\ (products)} - \Sigma n\Delta H^\circ_{f\ (reactants)}$$ where Σ = sum of; n = moles

Ex. 1 Calculate the heat of reaction for the formation of carbon dioxide from carbon monoxide gas and oxygen. (use the ΔH°_f table); remember, ΔH°_f of free elements = O. (–566.0 kJ)

Ex. 2: Benzene C_6H_6 is an important hydrocarbon. Find the heat of reaction for the combustion of benzene $C_6H_{6(l)}$: ΔH°_f (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 $SO_{2(g)}$ 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 ΔH_f° 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:

   $$2Al_{(s)} + Cr_2O_{3(s)} \longrightarrow Al_2O_{3(s)} + 2Cr_{(s)}$$

   (a) Calculate ΔH 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 (CH_3OH) 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 (C_8H_{18}) (–22.7, -48.7, –1454, -1.09×10^4)

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