Heats of Formation

What do the tabulated $\Delta H°_f$ values in the appendix of my textbook mean?

Why?

Enthalpies of formation, $\Delta H°_f$, are commonly tabulated in chemistry texts and reference materials. They are the most common way of calculating theoretical $\Delta H°$ values via Hess's law, but often the reaction that they refer to is not shown in the table. In this activity, we will explore these values, what they represent and how they can be used to predict the enthalpies of other reactions.

Model 1 – Comparing Reactions

Set A

	(kJ/mole)
$\frac{3}{2}O_2(g) + 2Al(s) \rightarrow Al_2O_3(s)$	–1675
$6C(graphite) + 6H_2(g) + 3O_2(g) \rightarrow C_6H_{12}O_6(s)$	–6984
$H_2(g) + \frac{1}{2}O_2(g) \rightarrow H_2O(l)$	–286
$\frac{1}{2}N_2(g) + O_2(g) \rightarrow NO_2(g)$	+33
$\frac{1}{2}H_2(g) + C(graphite) + \frac{1}{2}N_2(g) \rightarrow HCN(g)$	+131

Set B

	(kJ/mole)
$3O_2(g) + 4Al(s) \rightarrow 2Al_2O_3(s)$	–3350
$CO_2(g) + H_2O(l) \rightarrow C_6H_{12}O_6(s)$	+2805
$2H(g) + O(g) \rightarrow H_2O(l)$	–1121
$H^{1+}(aq) + OH^{1-}(aq) \rightarrow H_2O(l)$	–231
$2NO(g) + O_2(g) \rightarrow 2NO_2(g)$	–114

1. Consider the reactions in Model 1. What type of reaction are all of the examples in Model 1—synthesis, decomposition, single replacement, double replacement or combustion?

2. Compare the first reaction in each set (producing aluminum oxide).

   a. How are the reactions similar?

   b. How are the reactions different?

3. Compare the two sets of reactions in Model 1.

   a. Which set of reactions uses fractional coefficients to balance the equation, forcing the product to always have a coefficient of one?

   b. Which set of reactions uses only elements as reactants?

   c. Which set of reactions uses reactants that would not be stable substances (not their natural state)? For example, a single oxygen atom is not a stable entity.

4. A **formation reaction** is defined as a synthesis reaction where one mole of product is made from component elements in their natural state.

   a. Which set of reactions in Model 1 are formation reactions?

   b. Add a label to Model 1 indicating this set as a group of formation reactions.

5. Explain why the following reactions are **not** formation reactions.

   $Mg^{+2}(aq) + 2Cl^{-}(aq) \rightarrow MgCl_2(s)$

   $2Na(s) + 2H_2O(l) \rightarrow 2NaOH(aq) + H_2(g)$

   $2H_2(g) + O_2(g) \rightarrow 2H_2O(l)$

6. The numerical values in Model 1 are standard enthalpies for the reactions. Enthalpies for formation reactions are called standard heats of formation, and they are given the symbol $\Delta H°_f$.

   a. Label the column of enthalpies for the formation reactions $\Delta H°_f$.

   b. Label the column of enthalpies for the other reactions $\Delta H°$.

7. Are standard heats of formation endothermic, exothermic or both?

8. Consider what you know about the energy involved in breaking and forming bonds. Explain why some standard heats of formation might be endothermic?

Read This!

Your chemistry textbook probably has an appendix that tabulates standard heats of formation for many common substances. Rather than show the entire formation reaction, they simply list the compound that is formed. It is assumed that the user understands the reaction represented. Some of the values in the list are found by experiment, others are likely calculated indirectly from other data.

9. Find a table of standard heats of formation in your textbook or online.
   a. What is the ΔH°_f for solid sodium chloride?

   b. Write the reaction that involves that energy change.

   c. What is the ΔH°_f for gaseous iodine, I_2 (g)?

   d. Write the reaction that involves that energy change.

10. Explain why the ΔH°_f for gaseous oxygen, O_2 (g), is zero.

11. If a formation reaction was reversed, how could the standard enthalpy for that reaction be calculated from a standard heat of formation listed in the table? Illustrate your understanding by finding the ΔH° for the following reaction.

$$HBr(g) \rightarrow \tfrac{1}{2}H_2(g) + \tfrac{1}{2}Br_2(l)$$

12. If a formation reaction was multiplied by a factor, how could the standard enthalpy for that reaction be calculated from a Standard Heat of Formation listed in the table? Illustrate your understanding by finding the ΔH° for the following reaction.

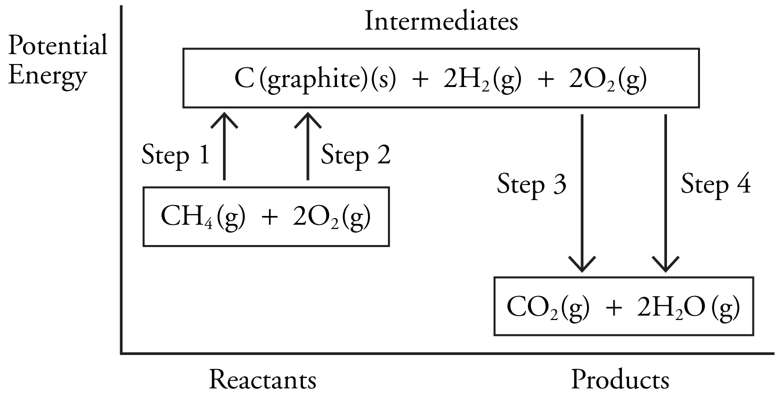
$$2Al(s) + 3Cl_2(g) \rightarrow 2AlCl_3(s)$$

STOP

Read This!

Standard heats of formation can be used to predict the enthalpies of many other reactions. Imagine that a reaction occurs by all reactants decomposing into elements in their natural state and then recombining to form the products. Although very few chemical reactions occur in this manner, it does not really matter. Enthalpy is a **state function**, which means it is determined only by the initial state of the reaction and the final state of the reaction, not the process that occurs in between. The enthalpy change that is calculated for our imaginary process will give us the enthalpy for the real-life reaction. Therefore, several formation reactions (or reverse formation reactions) can be combined using Hess's law to calculate the enthalpy for any reaction.

Model 2 – Calculating an Enthalpy, $\Delta H°$, from $\Delta H°_f$ Values



13. Write the reaction for the overall process in Model 2.

14. Notice that the intermediates in the process in Model 2 are elements in their natural states.

    a. Which steps in the process in Model 2 represent formation reactions, or multiples of formation reactions?

    b. Which steps in the process in Model 2 represent formation reactions, or multiples of formation reactions, in reverse?

15. Use a table of standard heats of formation to calculate the energy change when the reactants in Model 2 turn into the intermediates. Be sure to include the correct sign on this energy change.

16. Use a table of standard heats of formation to calculate the energy change when the intermediates in Model 2 turn into the products. Be sure to include the correct sign on this energy change.

17. Use your answers in Questions 15 and 16 to calculate the overall $\Delta H°$ for the process in Model 2.

18. Use what you have learned from Model 2 to calculate the standard enthalpy, $\Delta H°$, for the following reaction using a table of standard heats of formation. Show all calculations and be prepared to explain your process for solving this problem.

    $4NH_3(g) + 5O_2(g) \rightarrow 4NO(g) + 6H_2O(g)$

Extension Questions

19. The heat of combustion for 1 mole of propane, C_3H_8, at standard conditions is −2,046 kJ.

    a. Write a balanced chemical equation for the combustion of propane.

    b. Calculate the heat of formation, ΔH°_f, of propane given that the ΔH°_f of gaseous water is −242 kJ/mole and the ΔH°_f of carbon dioxide gas is −394 kJ/mole.

20. Which of the two formation reactions below would you predict to have the largest exothermic heat of formation? Justify your reasoning.

    $2Al(s) + O_2(g) \rightarrow Al_2O_3(s)$ $\qquad$ $Mg(s) + \frac{1}{2}O_2(g) \rightarrow MgO(s)$