Enthalpy of Formation

Unit: Thermochemistry (Heat)

MA Curriculum Frameworks (2016): HS-PS1-4

Mastery Objective(s): (Students will be able to…)

- Determine the enthalpy of formation for selected compounds by looking up data in a table.
- Identify the formation of compounds as spontaneous or non-spontaneous based on the sign of the enthalpy of formation.

Success Criteria:

- Enthalpy of formation has the correct sign and the correct units.
- Compounds are correctly identified as forming spontaneously and not forming spontaneously based on the sign of their enthalpies of formation.

Tier 2 Vocabulary: formation, spontaneous

Language Objectives:

- Explain how to find the enthalpy of formation of a compound.
- Explain how to determine whether formation of a compound is spontaneous or non-spontaneous.

Notes:

Although free energy is the best predictor of whether a reaction happens, focusing on just the changes in enthalpy can be more practical for several reasons.

1. Entropy cannot be measured, but must be calculated based on other measurements and calculations, such as enthalpy and equilibrium. For this reason, entropy numbers are difficult to obtain and are often not available for reactions of interest.
2. Free energy depends on the temperature. (Recall that $G = H - TS$) If a reaction is producing or consuming heat, the temperature will be changing during the reaction, which means free energy calculations will require careful measurements and complex, calculus-based equations. Enthalpy does not depend on temperature, which means enthalpy numbers can be used directly regardless of the temperature at which they were measured.
3. Enthalpy measurements can be used directly to calculate the thermal energy (heat) produced or consumed by a reaction.

Use this space for summary and/or additional notes:

The concept of enthalpy of formation is that if we define the enthalpy content of a pure element to be zero*, then:

- The enthalpy content of a compound can be measured by the reactions that produce the compound.
- The enthalpy content of a compound equals the heat energy released by forming its chemical bonds, and therefore also equals the heat energy needed to break those bonds.

standard enthalpy of formation: (ΔH_f^o) the amount of enthalpy (recoverable/usable heat) that is released when a compound is formed.

In the "Intermolecular Forces" section starting on page 313, we saw that it takes energy to break intramolecular bonds (bonds between one molecule and another), and forming those bonds releases energy. The same is true for intermolecular bonds (bonds within a molecule).

If a chemical compound forms spontaneously, it forms because the compound has less energy than the elements that it is formed from. When the compound is formed, the excess energy is given off as heat. Once that energy is released, there is no longer enough energy for the compound to spontaneously disintegrate, unless heat is added. These compounds have a negative enthalpy of formation.

In some cases, energy is required to form a chemical compound. In these cases, the compound is unstable, and when a small amount of energy is added to break the bonds, a larger amount of energy is released. These compounds have a positive enthalpy of formation.

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* Recall that enthalpy includes internal energy, which includes the energy of chemical and nuclear bonds, internal induced electric or magnetic dipole moment, stress-strain energy due to deformation of solids, *etc.*, as well as energy due to motion of the molecules, atoms, nuclei, electrons, *etc.* Saying that the enthalpy is zero does not mean we are ignoring these factors—remember that enthalpy can be negative. We are simply choosing the "zero point" to be the total of those energies in a pure element.

Use this space for summary and/or additional notes:

Determining Enthalpy of Formation

The enthalpy of formation is defined as the energy that would need to be *added* in order to form a compound or ion directly from its elements.

This means that pure elements in their natural state by definition have an enthalpy of formation of zero, because it takes no energy to form an element from its elements. This is true even for elements that are polyatomic in their natural state, such as N_2, O_2, Cl_2, F_2, Br_2, I_2, P_4 and S_8; even though these elements contain one or more chemical bonds, their enthalpy of formation is still defined to be zero.

If a compound or ion forms spontaneously, the process must *release* energy. This means that compounds or ions that form spontaneously have *negative* enthalpies of formation. (Adding negative energy is mathematically the same as releasing energy.)

Enthalpies of formation (ΔH_f^o) (and also entropies of formation) of selected compounds and elements are listed in "Table BB. Thermodynamic Data" in your Chemistry Reference Tables, on page 519.

Examples

The standard enthalpy of formation of $CaCl_2$ is $-795.8\,\frac{\text{kJ}}{\text{mol}}$. This means we would need to add $-798.2\,\text{kJ}$ to make one mole of $CaCl_2$ from elemental Ca and Cl_2. Adding a negative amount of heat means the reaction actually *releases* $795.8\,\frac{\text{kJ}}{\text{mol}}$ of heat. (Note that 795 kJ, or 795 800 J, is a lot of energy.)

The standard enthalpy of formation of C_2H_2 (acetylene) is $+226.7\,\frac{\text{kJ}}{\text{mol}}$. This means that acetylene does not form spontaneously, and we need to add 226.7 kJ of heat energy to produce one mole of acetylene gas. That energy will be released as heat when acetylene combusts to form CO_2 and H_2O.

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Homework Problem

Based on enthalpy of formation (ΔH_f^o) data in "Table BB. Thermodynamic Data" on page 519 of your Chemistry Reference Tables, rank the following ten compounds in order, from least stable to most stable.

$AgCl$, Al_2O_3, C_2H_2, H_2O, CO_2, N_2O, $CuSO_4$, H_2, $MgSO_4$, Si

1. _______
2. _______
3. _______
4. _______
5. _______
6. _______
7. _______
8. _______
9. _______
10. _______

Use this space for summary and/or additional notes: