

8.4: Standard States and Enthalpies of Formation

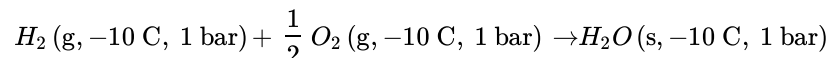
A useful convention makes it possible to tabulate enthalpy data for individual compounds in such a way that the enthalpy change for any chemical reaction can be calculated from the tabulated information for the reaction's reactants and products. The convention comprises the following rules:

I. At any particular temperature, **we define the standard state of any liquid or solid substance to be the most stable form of that substance at a pressure of one bar.** For example, for water at -10 C , the standard state is ice at a pressure of one bar; at $+10\text{ C}$, it is liquid water at a pressure of one bar.

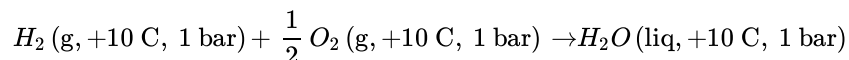
II. At any particular temperature, we define the standard state of a gas to be the **ideal gas standard state** at that temperature. By the ideal gas standard state, we mean a finite low pressure at which the real gas behaves as an ideal gas. We know that it is possible to find such a pressure, because any gas behaves as an ideal gas at a sufficiently low pressure. Since the enthalpy of an ideal gas is independent of pressure, **we can also think of a substance in its ideal gas standard state as a hypothetical substance whose pressure is one bar but whose molar enthalpy is that of the real gas at an arbitrarily low pressure.**

III. For any substance at any particular temperature, **we define the standard enthalpy of formation as the enthalpy change for a reaction in which the product is one mole of the substance and the reactants are the compound's constituent elements in their standard states.**

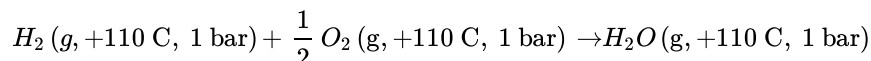
For water at -10 C , this reaction is



For water at $+10\text{ C}$, it is



For water at $+110\text{ C}$, it is



IV. The standard enthalpy of formation is given the symbol $\Delta_f H^\circ$, where the superscript degree sign indicates that the reactants and products are all in their standard states. The subscript, *f*, indicates that the enthalpy change is for the formation of the indicated compound from its elements. Frequently, the compound and other conditions are specified in parentheses following the symbol. The solid, liquid, and gas states are usually indicated by the letters “s”, “l” (or “liq”), and “g”, respectively. The letter “c” is sometimes used to indicate that the substance is in a crystalline state. In this context, specification of the gas state normally means the ideal gas standard state.

Thermochemical-data tables that include standard enthalpies of formation can be found in a number of publications or on the internet. For some substances, values are available at a number of temperatures. For substances for which less data is available, these tables usually give the value of the standard enthalpy of formation at 298.15 K. (In this context, 298.15 K is frequently abbreviated to 298 K.)

V. For any element at any particular temperature, we define the standard enthalpy of formation to be zero. When we define standard enthalpies of formation, we choose the elements in their standard states as a common reference state for the enthalpies of all substances at a given temperature. While we could choose any arbitrary value for the enthalpy of an element in its standard state, choosing it to be zero is particularly convenient.

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