# Gibbs Free Energy

## 4.5.1 \(\Delta G\) or the Change in the Gibbs Free Energy and \(\Delta S\_{\text{uni}}\)

When \(-\Delta H / T\) is substituted into the \(\Delta S\_{\text{univ}} = \Delta S\_{\text{surr}} + \Delta S\) equation for \(\Delta S\_{\text{surr}}\), the expression becomes \(\Delta S\_{\text{univ}} = -\Delta H / T + \Delta S\). If both sides of this equation are multiplied by \(-T\), the expression obtained is \(-T\Delta S\_{\text{univ}} = \Delta H - T\Delta S\). The term \(-T\Delta S\_{\text{univ}}\) is defined as the change in the Gibbs free energy or \(\Delta G\), where the symbol \(G\) refers to the Gibbs free energy—named for the American chemist J. Willard Gibbs, who first described it—and "free energy" because it represents the energy that is available or free to do work.

When the substitution \(\Delta G\) for \(-T\Delta S\_{\text{univ}}\) is made, we get the following expression:

\(\Delta G = \Delta H - T\Delta S\).

This final expression, \(\Delta G = \Delta H - T\Delta S\), is a restatement of the second law in terms of energy units, and in terms of the enthalpy and entropy changes of the system.

Gibbs Free Energy and the Second Law video

[transcript forthcoming]

## 4.5.2 \(\Delta G\) and Spontaneity

Since \(\Delta G\) is defined as \(-T\Delta S\_{\text{univ}}\), the value of \(\Delta G\) is directly related to \(\Delta S\_{\text{univ}}\), but has the opposite sign.

Consequently:

**\(\Delta G < 0\)** Spontaneous

**\(\Delta G = 0\)** at Equilibrium

**\(\Delta G > 0\)** Non-spontaneous

The change in the Gibb’s free energy or ∆G represents the total energy available to do work as a result of a chemical or physical change under constant temperature and constant pressure conditions.

The relationship, \(\Delta G = \Delta H - T\Delta S\), tells us that the entropy change of the system or \(\Delta S\) and of the surroundings or \(\Delta S\_{\text{surr}}\), which is given by \(-\Delta H / T\), directly impacts the Gibbs free energy or \(\Delta G\), which is the energy available to do work. If this equation is rearranged to \(\Delta H = \Delta G + T\Delta S\), we can see how \(\Delta H\) or the change in heat energy is related to \(\Delta G\) and \(\Delta S\). The total change in energy for the process is represented by \(\Delta H\). The entropy change of the system, as represented by the term \(T\Delta S\), directly affects the value of \(\Delta G\), because both the \(\Delta G\) and the \(T\Delta S\) terms combined must equal \(\Delta H\). Depending on its sign, positive or negative, the change in entropy of the system represents a decrease or an increase in the value of \(\Delta G\), which is the energy available to do work.

One way to look at this is if you were given a $100 gift certificate to Amazon and you found an item you wanted to buy that cost $100. Although you had enough credit on the gift card, if you checked out, you would come up short because of the added shipping and handling charges. However, if the item cost $95 and the shipping and handling came to $5, you would come out just right, but the buying power of the $100 you had to spend was only $95. However, if you had a credit or if the shipping and handling charge were waived, you would have the whole $100 or perhaps even a bit more to spend if you had a credit. Similarly, entropy is like the combined shipping and handling charge. Entropy must be paid or credited by the system and/or the surrounding to cover the “cost” of transporting energy between the system and the surroundings.

The relationship \(\Delta G = \Delta H - T\Delta S\) also tells us that the value of \(\Delta G\) is temperature dependent. Depending on the sign of \(\Delta S\), as the temperature increases, the \(-T\Delta S\) term becomes larger and adds to or subtracts from the value of \(\Delta G\). If the sign of \(\Delta S\) is positive, an increase in temperature results in a larger negative \(\Delta G\) value. If the sign of \(\Delta S\) is negative, an increase in temperature results in a smaller negative \(\Delta G\) value.

DeltaG and Spontaneity

[transcript forthcoming]

Applying the Second Law to Chemical Reactions

[transcript forthcoming]

## 4.5.3 Calculating \(\Delta G^\circ\) Values for Chemical Reactions from \(\Delta H^\circ\) and \(\Delta S^\circ\) Values and from \(\Delta G\_f^\circ\) Values

If we know the values of \(\Delta H^\circ\) and \(\Delta S^\circ\) or \(\Delta H\_f^\circ\) and \(\Delta S^\circ\), we can use the relationship \(\Delta G^\circ = \Delta H^\circ - T\Delta S^\circ\) to calculate the value of \(\Delta G^\circ\) or \(\Delta G\_f^\circ\) for a reaction. These values are typically listed in tables, so it is a relatively easy calculation. However, it is always important to remember that the value for \(T\) must be in Kelvin (K), and that \(\Delta H\) values are typically in units of kJ while \(\Delta S\) values are in J. So, the \(\Delta S\) J units need to be converted to kJ units before these terms can be combined.

Standard State Conditions and Delta G

[transcript forthcoming]

## 4.5.4 Using \(\Delta G\_f^\circ\) Values to Calculate \(\Delta G^\circ\_{\text{rxn}}\)

The \(\Delta G\_f^\circ\) values are state functions and, as such, can be treated like \(\Delta H\_f^\circ\) values to calculate the \(\Delta G^\circ\) value for a reaction. The example below outlines this process for the combustion reaction of methane. This process involves deconstructing the reactants back to their elemental building blocks, which requires changing the sign of \(\Delta G\_f^\circ\) values associated with each of the reactants. Then, recombining the resulting elements to form the reaction products. Lastly, the product \(\Delta G\_f^\circ\) values, which retain their signs, and the reactant \(\Delta G\_f^\circ\) values, with their reversed signs, are added together to obtain the \(\Delta G^\circ\) value for the overall reaction. This is shown in the diagram below, where the fat arrows depict the \(\Delta G\_f^\circ\) values and the narrow arrows depict the direction to or from the elements.

Image Credits

* Stephen Lower, Gibbs Function, chem1.com ([CC BY-SA 3.0](https://creativecommons.org/licenses/by-sa/3.0/)).

Read this online at <https://open.byu.edu/chem_101/jzzafghyng>