

## Spontaneous vs. Nonspontaneous

Gibbs free energy measures whether a reaction is spontaneous or not with the equation  $G = H - T S$ . Thus, based on whether  $H$  or  $S$  are positive or negative, the reaction may be spontaneous or nonspontaneous at low or high temperatures. It is useful to remember at what temperatures the reaction is spontaneous as written with varying enthalpy and entropy values. If  $H$  and  $S$  are both negative, the reaction is only spontaneous at low temperatures. This is because at low temperatures the entropy term will be a smaller positive number, making it more likely that the negative enthalpy can drive the spontaneity of the reaction. The opposite is true if  $H$  and  $S$  are both positive. In this case, a high temperature is needed to make the entropy term a large negative number, because the enthalpy change is positive. If  $H$  is negative and  $S$  is positive, the reaction is spontaneous at all temperatures because the change in Gibbs free energy is always negative. Contrastingly, if  $H$  is positive and  $S$  is negative, the reaction is nonspontaneous at all temperatures as written. This is because the change in Gibbs free energy is always positive.



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### Spontaneous at Low Temperatures

#### Spartan in the the Cold

Based on the equation for Gibbs Free Energy, there are certain reactions that are spontaneous at only low temperatures.

#### H is Negative

##### Delta-H-Horse Devil

If  $S$ , entropy, is negative, and  $H$ , enthalpy, is negative, the reaction is spontaneous at low temperatures. Based on the equation  $G = H - T S$ , we want Gibbs free energy to be negative. This requires a low temperature because a negative change in entropy makes that term positive. If the temperature is high, Gibbs free energy is more likely to be positive.

#### S is Negative

##### Delta-S-Snake Devil

If  $S$ , entropy, is negative, and  $H$ , enthalpy, is negative, the reaction is spontaneous at low temperatures. Based on the equation  $G = H - T S$ , we want Gibbs free energy to be negative. This requires a low temperature because a negative change in entropy makes that term positive. If the temperature is high, Gibbs free energy is more likely to be positive and the reaction is likely to be nonspontaneous.

### Spontaneous at High Temperatures

#### Spartan in the Heat

Based on the equation for Gibbs Free Energy, there are certain reactions that are spontaneous at only high temperatures.

#### H is Positive

##### Delta-H-Horse Angel

If  $S$ , entropy, is positive, and  $H$ , enthalpy, is positive, the reaction is spontaneous at high temperatures. Based on the equation  $G = H - T S$ , we want Gibbs free energy to be negative. This requires a high temperature because a positive change in enthalpy makes that term in the equation positive. If the temperature is high. In order for Gibbs free energy to be negative, the entropy term must be greater in magnitude than the enthalpy term, requiring a high temperature.

## S is Positive

### Delta-S-Snake Angel

If  $\Delta S$ , entropy, is positive, and  $\Delta H$ , enthalpy, is positive, the reaction is spontaneous at high temperatures. Based on the equation  $\Delta G = \Delta H - T \Delta S$ , we want Gibbs free energy to be negative. This requires a high temperature because a positive change in enthalpy makes that term in the equation positive. If the temperature is high. In order for Gibbs free energy to be negative, the entropy term must be greater in magnitude than the enthalpy term, requiring a high temperature.

## Spontaneous at All Temperatures

### Spartan at All Temperature

Some reactions are spontaneous at all temperatures depending on the values of enthalpy and entropy.

## H is Negative

### Delta-H-Horse Devil

If  $\Delta S$ , entropy, is positive, and  $\Delta H$ , enthalpy, is negative, the reaction is spontaneous at all temperatures. This is because based on the equation  $\Delta G = \Delta H - T \Delta S$ , Gibbs free energy would always be negative. Thus, the reaction would always be spontaneous.

## S is Positive

### Delta-S-Snake Angel

If  $\Delta S$ , entropy, is positive, and  $\Delta H$ , enthalpy, is negative, the reaction is spontaneous at all temperatures. This is because based on the equation  $\Delta G = \Delta H - T \Delta S$ , Gibbs free energy would always be negative. Thus, the reaction would always be spontaneous.

## Nonspontaneous at All Temperatures

### Nun-Spartan at All Temperatures

Some reactions will never be spontaneous as written based on the changes in entropy and enthalpy associated with them.

## H is Positive

### Delta-H-Horse Angel

If  $\Delta S$ , entropy, is negative, and  $\Delta H$ , enthalpy, is positive, the reaction is non spontaneous at all temperatures. This is because based on the equation  $\Delta G = \Delta H - T \Delta S$ , Gibbs free energy would always be positive and can never be negative. Thus, the reaction would always be nonspontaneous.

## S is Negative

### Delta-S-Snake Devil

If  $\Delta S$ , entropy, is negative, and  $\Delta H$ , enthalpy, is positive, the reaction is non spontaneous at all temperatures. This is because based on the equation  $\Delta G = \Delta H - T \Delta S$ , Gibbs free energy would always be positive and can never be negative. Thus, the reaction would always be nonspontaneous.